LIP detailed report/plan 2022/2023

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Foreword

Fundamental Science, International Collaborations, Europe, Portugal, LIP

Mário Pimenta
President

In the turmoil of current times, Fundamental Science is not at the top of the priorities of most governments and citizens. The sense of urgency is everywhere: in the War next door; climate change; environmental and natural catastrophes; energy crises; epidemics and other threats to health; the large fractions of Humanity that are hungry and struggling for survival; the daily rise of prices; the feeling that the future will be worse than the recent past. A century that began with the illusion that it would finally be the time for rationality and global progress is back to fragmentation, disputes, and personal and collective envy in search for local and global powers, the same spirit that led to unthinkable disasters in the first half of the 20th century.

The European Union is sailing through troubled waters, trying to promote short-term political consensus and to mitigate negative societal impacts. Portugal cannot be an exception, of course, but collectively minded, planned, long-term solutions are not usually part of our national traits: "Numa casa onde não há pão, todos ralham, e ninguém tem razão".

In fact the endless debate about whether a country like Portugal should promote public investment in Fundamental Science is back on the horizon.

In the past, in the eighties of the twentieth century, when Portugal became a full member of CERN, the main argument was that such an investment would be a luxury for a small and "poor" country, which would absorb a large fraction of the public investment in science, preventing the development of Applied Science, so necessary to national industry. History has fully demonstrated the opposite. Under the action of José Mariano Gago, the founder of LIP together with Armando Policarpo and Gaspar Barreira, Portugal joined many international scientific organizations and established many bilateral agreements as well. The development of all the Science in Portugal, Fundamental and Applied, was impressive.

Now, forty years later, the argument is more sophisticated: the scientific community in Portugal is already mature enough to find its own independent funding opportunities from international sources, thus avoiding to burden the chronically tight national public budget. Hopefully, as in the past, this point of view is not shared by the general public and the media. Sadly, it is shared by a non-negligible fraction of the scientific community itself, eager to increase the public support to short-term projects, even if at the cost of sacrificing long-term successful programs, and of sowing the seeds of discord.

LIP is, at its core and from the beginning, an institution of Fundamental Science with relevant activities and projects that have a strong and direct impact in society: in information technologies and data science and; in biomedical physics and health care; in space applications; in social physics; in education, advanced training and public outreach. Today LIP can be proud of its scientific record, as well as of its activities and societal impact in all these domains, which constitute the common achievement of LIP researchers, technicians, administrative personnel and of all the students that have been trained in the laboratory throughout the years. Today LIP is proud to have been able to go through the hard COVID-19 times, even increasing its activities and the number of Master and PhD students. But LIP is also aware that several aspects of its organization and running must be continuously improved, and that its exposure to the fickle public funding policies in science is too high. We count on, and we are thankful to, our international Advisory Committee, who each year review our activities in depth, recommending trajectory corrections and pointing out opportunities. Their help has been precious, and a heartfelt word of thanks has to be said to Pier Giorgio Innocenti, Christian Fabjan and Gigi Rolandi, who now terminate their already long-term commitment as LIP Advisory Committee members. And also a word of welcome to Werner Riegler, Jorgen D'Hondt, José Miguel Jimenez and Karoline Wiesner, who will now start their work in the committee.

In an ideal world, a long-term consensus between the Research Institutions, the Universities and the Government should have been reached long ago. A consensus which establishes, once and for many years, the organization, the responsibilities, and the duties of all. A consensus that defines the role of each in terms of scientific employment but also the associated core funding. Contract-programs should be established between FCT and the main research institutions that should be followed yearly by external referees, nominated by FCT for extended periods. Evaluation rounds happening every five years, with ever-changing criteria that are not followed even by the evaluation panels, should end. The evaluation of the institutions that form the backbone of research in Portugal in each scientific domain, with heavy employment responsibilities, cannot be treated as an evaluation within the calls for short-term projects or grants.

Science means cooperation and competition, and Fundamental Science based in international peaceful international collaboration is the main vector towards progress and Humanity.

Mário Pimenta

March, 2023

RESEARCH Areas and Lines

Experimental particle and **astroparticle physics**

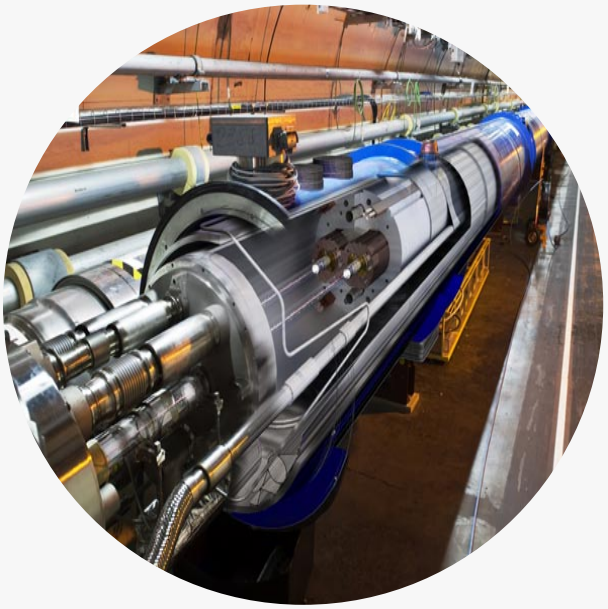
- LHC experiments and phenomenology...
- Structure of matter
- Cosmic rays
- Dark matter and neutrinos

Development of **new instruments** and **methods**

- Detectors for particle and nuclear physics
- Health and biomedical applications
- Space applications

Computing

- Scientific Computing



[LHC experiments and phenomenology]

ATLAS
CMS
Pheno
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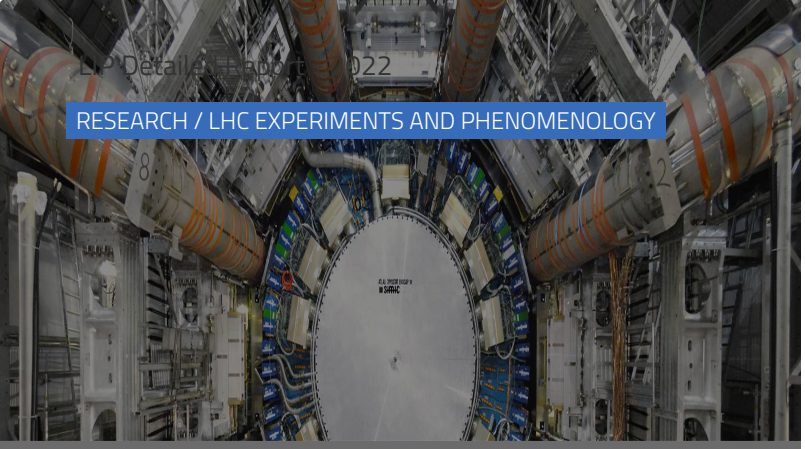


ATLAS

Collaboration in the ATLAS experiment at CERN

Principal Investigator:
Patricia Conde (70)

15 ***Researcher(s):***
Agostinho Gomes (80), Amélia Maio (30), António Onofre (20), António Pina (30), Filipe Veloso (80), Guiomar Evans (30), Helena Santos (75), Helmut Wolters (60), Inês Ochoa (60), João Gentil (20), Marcin Stolarski (30), Miguel Fiolhais (30), Nuno Castro (25), Ricardo Gonçalo (60), Rute Pedro (15)

5 ***Technician(s):***
Filipe Martins (100), Gabriela Pinhão (100), Luís Gurriana (80), Luís Seabra (100), Rui Fernandez (100)

7 ***PhD Student(s):***
Ana Luísa Carvalho (100), Beatriz Pinheiro Pereira (25), Luis Coelho (60), Maura Teixeira (100), Nuno Fernandes (100), Ricardo Barrué (100), Rudnei Machado (40)

8 ***Master Student(s):***
António Caramelo (21), Catarina Pereira (16), João Pedro Pires (50), Maria Miguel (21), Patrícia Ferreira (100), Pedro Lagarelhos (50), Rúben Inácio (24), Simão Costa (3)

19 ***Undergraduated Student(s) and Trainee(s):***
Afonso Azenha, Artur Semião, Beatriz Rosalinho, Beatriz Silva, Bruna Lima, Carolina Costa, Catarina Oliveira, Filipe Costa, Guilherme Gaspar, Inês Pinto, Joan Kladnik, Joana Ramos, Mariana Ribeiro, Nuno Gonçalves, Sinead Eley, Tiago Prates da Costa, Ulrich Willemsen, Vanessa Pinto, Vicente Mendes

12 ***External collaborator(s):***
Ana Peixoto, André Wemans, Daniel Neacsu, Helena Macedo, José Cordeiro, José Rufino, José Soares Augusto, Mikael Chala, Pedro Jorge, Rui Santos, Susana Sério, Tiago Vale

Total FTE:
20.2 (PhD 7.1)

Articles in international journals:	**3** Direct contribution **39** Indirect contribution
Notes:	**4** Collaboration notes **3** LIP Students notes
International conferences:	**10** Oral presentations **1** Poster **5** Proceedings
National conferences:	**1** Oral presentation
Nat.& Internat. meetings:	**6** Oral presentations **6** Posters
Collaboration meetings:	**89** Oral presentations
Advanced Training Events:	**7** Oral presentations **3** Student presentations
Seminars:	**1** Seminar **3** Outreach seminars
Completed theses:	**1** MSc
Organized Events:	**1** Collaboration Meeting

Executive summary

The LIP Portuguese group was a founding member of the ATLAS Collaboration and has made significant contributions to the detector and Trigger/DAQ design, construction, commissioning and operations. The most important of these were in the TileCal hadronic calorimeter, forward detectors and jet trigger software. Since the beginning of the LHC, we have contributed to detector operation, performance studies, and physics analysis. The group contributed directly to the Higgs boson discovery and is now measuring its properties. It is a reference in top quark physics studies and has exploited this expertise to lead several searches for new physics. The group has also given important contributions to the ATLAS heavy ion physics programme by studying jets as probes of the quark-gluon plasma (QGP).

In 2022, the Run 3 of the LHC took off and ATLAS started taking data after a period of maintenance and upgrades (long-shutdown LS2). The high luminosity phase HL-LHC is scheduled to start in 2029 and being actively prepared by both the accelerator and the experiments.

Currently, we are a strong team that impacts all the areas of activity where we are involved. We are fully responsible for the detector control system (DCS) of TileCal, coordinating the Calibration group and contributing to operations and maintenance, calibration and data quality monitoring. Concerning the Upgrades for the HL-LHC, we have full responsibility for designing and producing the High Voltage (HV) distribution system. We lead performance studies such as ageing of the optical components and its effects, and contribute to new TileCal usages for background jet rejection at trigger level.

With respect to the forward detectors, we are co-leading the AFP DCS group, with responsibility for the vacuum and movement systems, and we are fully responsible for the ALFA DCS.
We have recently joined the High Granularity Timing Detector (HGTD), with responsibilities in the DCS and interlock systems, front-end ASIC tests and the design and production of patch panels for the HV system.

On the trigger side, in the last few years our focus has been the optimisation and readiness of the jets triggers for Run 3, and the development of the Central Exclusive Production (CEP) di-jets triggers, a key process to exploit and demonstrate the AFP triggering capabilities. For the future, we are the reference group developing calorimeter reconstruction algorithms using Graphical Processing Units (GPUs) as accelerators.

As for physics analyses, we are exploiting the Run 2 dataset with precision measurements in the Higgs and Top quark sectors (Higgs couplings to the b- and t- quarks, and to the W bosons), searches for new particles and interactions (dark matter in monotop topologies, di-boson resonances) and the study of the QGP with heavy quarks as probes. In addition, we are applying anomaly detection techniques to find new physics, and we play a leading role in the LHC Effective Field Theory working group and in the ATLAS di-boson searches group. Our expertise in Machine Learning (ML), hadronic calorimetry, boosted boson and b-jet tagging is the common glue supporting all these activities.

Last but not least, we contribute to the ATLAS Distributed Computing and to the official Physics Office Software. We have fruitful collaborations with LIP's research infrastructures and competence centers (namely the Computing Group, LOMaC, eCRLab and the Big Data CC) and with other research groups, in particular the Phenomenology group.

In 2022 we welcomed 250 members of the ATLAS Collaboration at the Aula Magna of the University of Lisbon, for the October ATLAS Collaboration Week, during which the 30th anniversary of the collaboration, was celebrated. We organised two public events associated with the ATLAS Week and contributed to the organisation of a public event to celebrate the 10th anniversary of the Higgs boson discovery.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Inês Ochoa	Fundação La Caixa	297.900 €	2020-07-01 to 2023-11-27	"La Caixa" Postdoctoral Junior Leader Fellowship
Patricia Conde (Nuno Castro)	FCT	165.000 €	2021-09-01 to 2023-08-31	CERN/FIS-PAR/0010/2021 / Collaboration in the ATLAS experiment at CERN
Ricardo Gonçalo (Agostinho Gomes)	FCT	192.672 €	2021-10-01 to 2023-09-30	CERN/FIS-PAR/0026/2021 / Collaboration in the ATLAS Upgrade

ATLAS

Overview

The team is structured in subgroups led by senior physicists (in brackets below), following the organisation structure of the ATLAS activities:

Physics Analysis

- Precision Measurements (R. Gonçalo). We are making leading contributions to the study of the Yukawa coupling of the Higgs boson to the b- and t-quarks as well as studying the Higgs coupling to W bosons (including the spin and CP properties in the coupling vertices). We also develop improved methods to identify boosted H→bb decays, the kinematic region most sensitive to anomalous couplings. We aim at using these results to search for new physics in the context of an effective field theory approach, and N. Castro is leading this effort in the LHC Community.
- Direct searches for new physics phenomena (N. Castro). We are searching for vector-like quarks, predicted by some of the extensions of the SM as a way to regulate the Higgs mass. We are leading the search for flavour changing neutral currents associated with the tZq vertex and the search for monotop events, which can probe dark matter production at the LHC. I. Ochoa led (April 2020 - April 2022) the physics subgroup searching for new physics in the TeV scale in final states with multiple vector and/or Higgs bosons. Our group also contributes to the searches for new physics phenomena using anomaly detection tools in data.
- Heavy ion physics (H. Santos). Our long term goal is to understand the mechanism of the jet energy loss in the QGP using jets as probes. As a first step towards that, we are developing tools for heavy-flavour jet tagging.

M&O and performance of the ATLAS detector and trigger system

- TileCal (A. Gomes, R. Pedro). We are leading the development, maintenance and continuous upgrade of the DCS system (F. Martins) and the TileCal calibration groups (R. Pedro). We lead performance studies such as ageing of the optical components, and contribute to the laser calibration and to new TileCal usages for background jet rejection at trigger level (TileMuon trigger).
- Jet Trigger (R. Gonçalo). We are one of the key contributors to the jet trigger operations, monitoring and development.
- Forward Detectors (P. Conde, N. Castro). We are leading the DCS of the ARP (ATLAS Roman Pot) detectors (L. Seabra). In ALFA, we are responsible for the full system, and in AFP our responsibility is the vacuum, cooling and movement controls. In addition, we contribute to the design and implementation of the high-level trigger software.
- GRID Distributed Computing (H. Wolters). We contribute to the development and support of the ATLAS Distributed Computing operations, such as monitoring software and shift organisation. We coordinate the Iberian Cloud and the Portuguese Federated Tier2 in the Iberian Cloud Squad.

Detector Upgrades

- TileCal Upgrade (A.Gomes, A. Maio). We are responsible for producing the new TileCal high-voltage distribution system for Phase II.
- High level trigger system (P. Conde, R. Gonçalo). We are developing a GPU-accelerated version of the offline calorimeter clustering algorithm TopoCluster. This is an important step in the reconstruction of several physics objects.
- HGTD (R. Gonçalo). We are contributing to several components of the ATLAS High Precision Timing Detector:
  - Development of the ALTIROC front-end ASIC
  - Design of the DCS and Interlock systems, including designing and building some of the electronics
  - Design and production of the patch panels for the High Voltage distribution system.

The Portuguese team is represented as follows in ATLAS collaboration bodies:

- ATLAS National Physicist Board (P. Conde)
- ATLAS Collaboration Board (P. Conde)
- ATLAS International Computing Board (H. Wolters)
- TileCal Institutes Board (A. Maio, A. Gomes)
- Trigger/DAQ Institutes Board (R. Gonçalo)
- Forward Detectors Board (P. Conde, N. Castro)
- HGTD Institutes Board (R. Gonçalo)
- TileCal Phase II Upgrade Steering Committee (A. Gomes)

Assessment of the past year: objectives vs. achievements

Physics studies

Precision measurements:

- Finished the study of optimal observables defined at detector level using ML inference-based methods on the searches for anomalous Spin/CP components in the hWW vertex. The results demonstrate that angular observables combined with the W transverse momentum measurement provide better sensitivity for the ATLAS Run 2 and Run 3 analysis.
- The implementation of these methods on the Run 2 Legacy measurement of WH (with H → bb) is about to start.

- The first CP-sensitive analysis of ttH production with the Higgs decaying to b-quark pairs, that was led by our group in the semileptonic channel, was published as an ATLAS public note and an article will soon follow (it is now in the final stage of internal collaboration review before submission to the journal).
- Contributed to the ttH (H → bb) Run-2 legacy paper: optimization of the control regions using c-tagging and a leading contribution to the combined fit (modelling of the systematics and their effects on the fits). PhD student Ana Luísa Carvalho is editor of this publication.
- Given the very large normalisation corrections of the ttc background in many ttH analyses, we started contributing to the measurement of the ttc production. Ana Luísa Carvalho is the leading force of this analysis in the dileptonic channel and has developed the analysis strategy and all the fit infrastructure and fit studies.
- A new X→ bb tagger that uses jet substructure variables was prepared, resulting in a 30% increase in the background rejection. Possible sculpting of the invariant mass distribution of this (and other) taggers is under study.
- Continued collaborating with SLAC to explore graph networks for vertexing algorithms to improve b-tagging and H→bb tagging capabilities at higher energies. Preliminary results are encouraging and a master thesis project (targeting summer 2023) is being carried out on this topic.
- Continue leading and actively contributing to the effective field theory interpretation of different precision measurements in the top quark sector.

Direct searches for new physics phenomena:

- Continued the search for monotop (t+MET) events with full Run 2 data, publishing the corresponding paper.
- Continued the studies of anomaly detection techniques for model-independent searches at ATLAS, using fully hadronic topologies.
- Contributed to the combination of heavy resonance searches with responsibility for the VH statistical analysis. A preliminary result was made public for Moriond 2022. The target date for a paper was postponed to 2023 in order to include a wider range of analyses in the combination.
- Completed the 2D resonance search in the Y → XH channel using the full Run 2 data and anomaly detection methods. A preliminary result was made public for ICHEP 2022 and the search is on track for a publication date in early 2023. This search employs two novel methods (Higgs boson tagging and anomaly tagging) and the delay of one year was largely due to the calibration work necessary for the Higgs boson tagging.

Heavy Ion physics:

- We studied the performance of the DIPs and DL1 DNN b-tagging algorithms and applied a new variable to improve the performance in central collisions;
- The systematic studies on the performance of the algorithms running on CPUs and GPUs were postponed due to infrastructure limitations.
- The heavy-flavour jet production studies are delayed due to other priorities of the main analyser (now member of the Publications Committee and contributing to HGTD).

Detector maintenance, operation and upgrade

Forward Detectors:

- ALFA DCS: a new Windows machine running a WinCC project was installed outside ATLAS network to allow PLC control and monitoring. PLC monitoring to the DCS main project was ensured through DIM communication. General upgrades and test system support were provided.
- AFP DCS: a new software interlock for the vacuum system in case of a vacuum failure was installed and tested. General upgrades for the cooling, movement and vacuum systems were implemented.
  Provided DCS support during data taking and detector operations.
- CEP triggers:
  - Validated the track reconstruction at trigger level for the AFP detector (working exactly as in offline).
  - The validation of the CEP-dijet trigger chains is still ongoing.
  - Implemented the CEP soft di-lepton triggers for new physics searches. Validation is ongoing.

TileCal Operations and Performance

- DCS:
  - The migration to the latest WINCC OA version of of the SCADA systems located at the test benches (laboratories) was performed and should be installed as soon as possible;
  - Contributed to the operation of the detector by:
    - Very active active role on DCS expert on-call shifts and being the backup of the DCS expert on-call shifter (24/7);
    - Fixing the DCS software during 2022 data taking period;
    - Updating on-call documentation and providing training during 2022 for on-call shifters;
    - Designing and developing a control system for a new type bulk High Voltage Power Supply (HVPS) able to

provide 830 V or 950 V, which can be used as replacement of the current bulk HVPS. These HVPS are currently under tests with special focus on the operation and fault handling.

- Data Quality activities: maintained regular contribution with 1 DQ leader and 2 DQ validator shifts.
- Optics radiation hardness:
  - Finalised run-2 analysis of the ageing of the Tilecal optical components and explored Cesium calibration data at a sub-cell level, proving that it leads to increased precision on the estimates of the expected light yield at the end of the HL-LHC phase. Reported this study in an internal note. The study of the Run 3 data will start soon.
  - The results were included in the TileCal Run 2 operations and performance paper (under internal review).
  - The simulation of the effects of optics degradation in TileCal Performance in the HL-LHC was not initiated due to person power limitations (put on hold).
- Calibration:
  - Coordinated the calibration teams, and overviewed the procedures, software and operations on the first year of data taking in the LHC Run 3.
  - Laser calibration: contributed to the weekly calibration of the detector and completed the internal review of the Laser run-2 paper (lead by R. Pedro).
  - Contributed to the ATLAS paper on the luminosity measurement using the calorimeter amongst other systems.

TileCal Phase II Upgrade:

- HV:
  - Produced final prototypes of HV supplies boards - in collaboration with LIP's eCRLab - and designed the last prototype of the HVremote boards.
  - The vertical slice test of the HV system was almost completed. The first testbeam in 2023 will integrate the few missing elements that were tested at the lab also in almost complete systems.
  - The HV cable prototype with 12 pairs of wires passed all tests but at the end of the year the central management of General Cable decided to discontinue the respective production line. New slightly different cables are being designed for another production line.
  - The Production Readiness Reviews of the HV packages was conditionally passed due to the uncertainty on the new cables production.
  - Designed the boards for the test benches for the quality control of the HV boards and cables. The components of these boards were purchased.
  - The control of HV boards was migrated to work at HV crate level. Further tests are required for stable and final integration.
- Low Voltage DCS:
  - The design of the control components for the Auxiliary boards is progressing and the latest hardware modifications were applied. The initial version of this control is being used at the test beam.
  - The development of the SCADA component for the LV system is in progress and the final mapping of analog input channels has now been established.
- Tile-Muon trigger:
  - Started the preparation of the simulation studies for the HL-LHC phase by developing an analysis of the trigger performance and its stability during Run 2.

Jet Trigger preparations for Run 3:

- We contributed to the optimisation and performance studies of the Jet Trigger for the Run 3, comparing different reconstruction techniques such as particle flow versus calorimeter reconstruction, different primary vertex reconstruction methods or the impact of adding a calorimeter-only preselection step at trigger level.
- Contributed to the trigger desk and run control shifts in the ATLAS control room.
- Strong contribution to the development of the global trigger menu and expert shifts. One out of the five ATLAS persons doing the trigger expert shifts (24h/day, 7 days/week during 9 months) is a member of our group.

Trigger Phase II Upgrade:

- Considerably advanced the development of the GPU-accelerated calorimeter reconstruction:
  - Detailed performance comparisons between the GPU and CPU versions of the TopoCluster growing algorithm, in single thread and multithreaded mode, led to significant improvements in the cluster reconstruction. The differences with respect to the CPU version are now negligible.
  - Implemented automatic monitoring/validation tests.
  - Designed and implemented a new, more performant version of the TopoCluster splitter algorithm. The combination of the growing+splitting gives time execution gains of a factor 10. As a consequence of this achievement (that was not included in the plan last year), the implementation of a realistic GPU-accelerated calorimeter trigger chain was postponed.

HGTD detector development - in collaboration with LIP's eCRLab and Detectors Lab:

- Contributed to the electronics work package:
  - Contributed to the development of the Altiroc front-end ASIC: a test setup was installed in the eCRLab and used

    to characterise version 2 of the ASIC, including signal to noise levels and thermal testing;
  - The HV patch panels/filters design (done by the Detectors Lab in Coimbra) passed the preliminary design review and a prototype is currently being produced for quality assurance before pre-production;
- Contribute to the Luminosity, DCS and Interlock package:
  - Coordinated the Interlock system, contributing to the system design. Currently designing the Transfer Module of the Main Interlock Crate, in view of future production;
  - Participating in the design of the DCS system, focusing on the electronics for monitoring the detector operating temperature and CO_2 cooling system.

Glance/Fence databases development:

In addition, we participate since September 2021 in the development of new functionality for the Glance/Fence databases. These DBs are vital for the organisation and life of the collaboration since they store and provide all personal and institutional information, responsibilities within the collaboration, account of technical work, publication procedures, nominations for conferences, etc.

Distributed computing

The group maintained the ADC Site Status Board and guaranteed its stability, organised the Computing Run Coordination, and operated the Portuguese Tier2 during the data taking.

Outreach and advanced training

We contributed to the organisation and support of outreach and education activities such as Masterclasses, seminars and internship programmes.

During the October ATLAS Week in Lisbon we celebrated the 30th anniversary of ATLAS and organised two public events, in collaboration with the LIP-ECO team. In the Ciência Viva science center in Lisbon, the movie "Particle Fever," was screened. This was followed by a questions and answers session with the participation of spokesperson A. Hoecker and other ATLAS scientists. A "Universal Science" session, with S. Goldfarb as moderator and the participation of ATLAS and LIP colleagues was hosted at the Aula Magna of the University of Lisbon.

Lines of work and objectives for next year

Physics studies

Precision measurements:

- Publish the results obtained for the ML-based optimal observables.
- Contribute to the Run 2 Legacy paper on the measurement of the H → bb decays in VH production.
- Develop the ATLAS analysis of the Spin/CP properties of the HWW vertex in the WH channel, with H → bb.
- Publish the CP-sensitive analysis of ttH production early in 2023.
- Contribute to the ttH (H → bb) Run 2 legacy paper: including the c-tagging calibration, ML methods, and increasing the sensitivity of the CP measurement.
- At a lower level (due to the need for PhD thesis writeup) contribute to the ttc production analysis.
- Study and correct systematic effects of the X → bb taggers.
- Publish work on the graph networks for vertexing algorithms in collaboration with SLAC with the goal of improving b-tagging and H→bb tagging capabilities at higher energies, and incorporating these into future developments of the ATLAS X → bb tagger.
- Continue leading and contributing to the effective field theory interpretation of precision measurements in the t quark sector.

Direct searches for new physics phenomena:

- Finalise and publish the combination of heavy resonance searches with full Run 2 data.
- Publish the 2D resonance search in the Y → XH channel with full Run 2 data, anomaly detection and new Higgs tagging algorithm.
- Continue the search for monotop (t+MET) events with full Run 2 data, publishing the corresponding paper.
- Continue the studies of anomaly detection techniques for model-independent searches in fully hadronic topologies.

Heavy Ion physics:

- We will continue our contributions to the software of the DNN, mostly in heavy ion collisions;
- We will make the study of the performance of the DL1d DNN algorithm (improved version of DL1) and search for methods to improve the performance in central collisions;
- Systematic studies on the performance of the algorithms running on CPUs and GPUs are foreseen.

Detector maintenance, operation and upgrade

Forward Detectors:

- ALFA DCS: Test system upgrade with a new machine and a new version of the WinCC. Damage evaluation and recovery after water leak. Preparation for 2023 data taking and detector removal ending ALFA operation. General upgrades and documentation.
- AFP DCS: General upgrades for the cooling, movement and vacuum systems.
- Provide DCS support during data taking and detector operations.
- CEP triggers:
  - Validate the CEP di-jet triggers for data taking (performance studies with simulated data and first collisions).
  - Develop CEP soft di-lepton triggers for new physics searches.

TileCal Operations and Performance

- Continue taking full responsibility of the DCS by:
  - Performing DCS expert on-call shifts and backup of the DCS expert on-call shifter (24/7).
  - Continuous upgrade and debugging of the DCS software.
  - Provide adequate training for the new on-call shifters while updating existing documentation when needed.
  - Assist the maintenance teams during the technical stop.
  - Migration of low voltage system controls to operate with the new CANopen OPC UA.
  - Complete the tests with the new bulk high voltage power supply (legacy system).
- Maintain regular contributions to the data quality activities with validator and leader shifts.
- Optics radiation hardness studies:
  - Finish the internal note reporting the Run 2 study and prepare a dedicated journal publication.
  - Start ageing monitoring with Run 3 data, studying also the scintillator recovery between Run 2 and Run 3, and the degradation suffered by the different material types.
- Calibration: finish the publication of the laser Run 2 paper and contribute to the photodetectors calibration.
  - Co-coordinate the HL-LHC Performance Studies group.

TileCal Phase II Upgrade:

- HV:
  - Correct the errors in the final design of the prototypes of HVremote and FPGA interface boards.
  - Finish the vertical slice test of the complete HV system at the test beam in June.
  - Start pre-productions (depending on components availability).
  - Produce test benches for the quality control of the HV boards and cables.
  - Proceed with the tests of the controls of the HV Remote crates (focus on the crates software).
- LV DCS:
  - Integrate AuxBoard and finger Low Voltage Power supply controls (test also with new CAN Open OPC UA).
- Tile-Muon trigger:
  - Conclude long term stability of TileMu trigger during Run 2 and analysis of Run 3 data (analog output).
    Monte-Carlo studies for the HL-LHC with digital output.

Jet Trigger:

- We will continue our strong support for the trigger shifts in the control room and expert shifts (on call).
  Finish the performance studies with first run-3 data and publish the results.

Trigger Phase II Upgrade:

- Continue the development of the GPU-accelerated calorimeter reconstruction:
  - Finish the correction of the remaining differences between the GPU and CPU versions of the cluster growing + splitter algorithms.
  - Port the cluster moments calculation to the GPU (improving the overal time performance gain).
  - Implementation of a realistic GPU-accelerated trigger chain including the GPU-accelerated TopoCluster reconstrucion and ID tracking.

HGTD detector development - in collaboration with LIP's eCRLab and Detector Lab:

- Electronics work package:
  - Get the HV patch panels/filters to the pre-production stage.
  - Test version 3 of the front-end ASIC in view of pre-production, including performance characterisation and irradiation tests.
- Luminosity, DCS and interlock systems:
  - Design and implement carrier board for DCS temperature readout.
  - Design and test a prototype Transfer Module for the Interlock system.

Distributed computing

- We will further improve the ADC Site Status Board and continue our responsibilities in the operation of the Iberian cloud infrastructure and the Portuguese Tier2 and in the organization of the Computing Run Coordination shifts.

Glance/Fence databases:

- New versions of the ATLAS Publication Tracking system and SCAB Nominations will be deployed, improving the functionality.
- A new system to manage photos permissions and visualisation within Glance will be developed.

Outreach and advanced training

- We will maintain the level of involvement in the organisation and support of outreach and education activities such as Masterclasses, seminars and internship programmes.

Medium-term (3-5 years) prospects

The LHC is expected to complete Run 3 in 2025. A shutdown period will follow to prepare for HL-LHC scheduled to start in 2029.

In terms of proton-proton collisions physics, our main objectives are focused on precision measurements of the Higgs couplings, including spin/CP properties of the interaction vertices, precision measurements in the top quark sector and direct searches for new physics. Both the studies of the top quark and Higgs properties are fundamental to probe the limits up to which the SM provides an accurate description of nature. The strategy is complemented by direct searches for new exotic particles, such as vector-like quarks, additional scalars, vector bosons, or gravitons. We aim at enhancing the sensitivity to new physics by improving the reconstruction and analysis techniques of the boosted H → bb decays and new physics searches using advanced ML methods. Regarding the heavy ion physics programme, our main objective for the next few years is to probe the nature of the energy loss of partons as they traverse the QGP by measuring the modification of b-jets production.

The group will keep its commitments in detector maintenance and operations in the TileCal, jet trigger system and forward detectors. A strong effort will be dedicated to the detector upgrades in these three systems and in the High Granularity Timing Detector (HGTD). Regarding the TileCal, the main endeavour will be the full production of the new HV distribution system for the Phase II Upgrade, involving Portuguese industry, and the continuous upgrades of the DCS. Systematic studies of the ageing of optical components (scintillators and fibres) and its impact on the expected performance of the detector (jet measurement and electron identification) will complete this effort. On the trigger side, the focus will be on the software, with the development of advanced real-time algorithms that use hardware accelerators (such as GPUs). In the HGTD we have responsibilities in the DCS and Interlock systems and the production of patch panels for the HV distribution system.

SWOT Analysis

Strengths

The group holds know-how in calorimetry, DCS, software triggers and physics analyses. We have a very close connection with LOMaC, a laboratory dedicated to calorimetry instrumentation, preparation, quality control and characterisation of optical fibres, plastic scintillators and photodetectors. There is also expertise in electroncis, namely in eCRLab and Detectors Lab. LIP's research infrastructures further provide access to distributed computing infrastructures and expertise in advanced computing. We have also a fruitful collaboration with the Phenomenology group at LIP.

Our long expertise in top quark physics has driven us to lead many studies of top quark properties and searches for exotic new physics phenomena. We have expertise in Higgs and Heavy Ions physics. Our know-how in Machine Learning, jet reconstruction and calibration, boosted boson and b tagging is a common denominator for all these activities.

Weaknesses

The reduced number of postdocs and early career researchers, reflecting a national problem in scientific employment, limits the possibility of expanding the group's impact.

The number of new Master and PhD students is unstable, and low in some of the LIP nodes. The effort to attract new students to all the activity areas should continue.

Opportunities

We are a national team with connections to many of the universities in the country, placing us in an optimal situation to strengthen our relationship with the universities and attract new students.

The Portugal-CERN PhD grants program, together with the challenges of the LHC Upgrade and the physics potential of Run 2 and Run 3 continue to provide an excellent framework for high-level students in all areas, including technical research topics.

The growth in LIP of phenomenology and data science fields has proved to be an excellent opportunity for synergies.

Threats

The human power situation of the group continues to be delicate, particularly in what concerns technicians and postdocs. The instability and level of the funding do not ensure medium- or long-term support in this area. The situation may become critical if key persons leave the group.

The overall price inflation (e.g. in electronics components) and the uncertainty on the funding for the coming years is a serious threat, particularly for our upgrade activities.

ATLAS

Publications

3 Articles in international journals (with direct contribution from team)

- *"Search for pair-production of vector-like quarks in pp collision events at s√=13 TeV with at least one leptonically decaying Z boson and a third-generation quark with the ATLAS detector"*, N. Castro, T. Vale et al. (ATLAS Collaboration), PLB, arXiv:2210.15413
- *"Upgrade of the ATLAS Tile Calorimeter high voltage system"*, A. Gomes, J. S. Augusto, F. Cuim, G. Evans, R. Fernandez, L. Gurriana, R. Marques, F. Martins, C. Pereira (ATLAS Tile Calorimeter Group), J. Instrum. 17 (2022) C01061
- *"Measurement of Higgs boson decay into b-quarks in associated production with a top-quark pair in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, J. High Energy Phys. 6 (2022) 097

39 Articles in international journals (with indirect contribution from team)

- *"Performance of the ATLAS Level-1 topological trigger in Run 2"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 7
- *"Search for single top-quark production via flavour-changing neutral currents at 8 TeV with the ATLAS detector (vol 76, 55, 2016)"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 70
- *"Measurement of the c-jet mistagging efficiency in t(t)over-bar events using pp collision data at root s=13 TeV collected with the ATLAS detector"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 95
- *"Operation and performance of the ATLAS semiconductor tracker in LHC Run 2"*, ATLAS Collaboration, J. Instrum. 17 (2022) P01013
- *"Search for heavy particles in the b-tagged dijet mass distribution with additional b-tagged jets in proton-proton collisions at p root s=13 TeV with the ATLAS experiment"*, ATLAS Collaboration, Phys. Rev. D 105 (2022) 012001
- *"Search for new phenomena in three- or four-lepton events in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Phys. Lett. B 824 (2022) 136832
- *"Search for Higgs boson decays into a pair of pseudoscalar particles in the bb mu mu final state with the ATLAS detector in pp collisions at root s=13 TeV"*, ATLAS Collaboration, Phys. Rev. D 105 (2022) 012006
- *"Search for exotic decays of the Higgs boson into b(b)over-bar and missing transverse momentum in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, J. High Energy Phys. 1 (2022) 063
- *"Observation of electroweak production of two jets in association with an isolated photon and missing transverse momentum, and search for a Higgs boson decaying into invisible particles at 13 TeV with the ATLAS detector"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 105
- *"The ATLAS inner detector trigger performance in pp collisions at 13 TeV during LHC Run 2"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 206
- *"Measurement of the energy response of the ATLAS calorimeter to charged pions from W-+/- → tau(+/-) (→pi(+/-)nu(tau))nu(tau) events in Run 2 data"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 223
- *"Search for Higgs bosons decaying into new spin-0 or spin-1 particles in four-lepton final states with the ATLAS detector with 139 fb(-1) of pp collision data at root s=13 TeV"*, ATLAS Collaboration, J. High Energy Phys. 3 (2022) 041
- *"Search for flavour-changing neutral-current interactions of a top quark and a gluon in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 334
- *"Measurement of the energy asymmetry in t(t)over-barj production at 13 TeV with the ATLAS experiment and interpretation in the SMEFT framework"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 374
- *"Constraints on Higgs boson production with large transverse momentum using H → b(b)over-bar decays in the ATLAS detector"*, ATLAS Collaboration, Phys. Rev. D 105 (2022) 092003
- *"Search for resonant pair production of Higgs bosons in the b(b)over-barb(b)over-bar final state using pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Phys. Rev. D 105 (2022) 092002
- *"Determination of the parton distribution functions of the proton using diverse ATLAS data from pp collisions at root s=7, 8 and 13 TeV"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 438
- *"Search for single production of a vectorlike T quark decaying into a Higgs boson and top quark with fully hadronic final states using the ATLAS detector"*, ATLAS Collaboration, Phys. Rev. D 105 (2022) 092012
- *"Search for neutral long-lived particles in pp collisions at root s = 13 TeV that decay into displaced hadronic jets in the ATLAS calorimeter"*, ATLAS Collaboration, J. High Energy Phys. 6 (2022) 005
- *"Measurements of azimuthal anisotropies of jet production in Pb collisions at root(NN)-N-s=5.02 TeV with the ATLAS detector"*, ATLAS Collab., Phys. Rev. C 105 (2022) 064903
- *"Measurement of the nuclear modification factor for muons from charm and bottom hadrons in Pb plus Pb collisions at 5.02 TeV with the ATLAS detector"*, ATLAS Collab., Phys. Lett. B 829 (2022) 137077
- *"Search for associated production of a Z boson with an invisibly decaying Higgs boson or dark matter candidates root s=13 TeV with the ATLAS detector"*, ATLAS Collab., Phys. Lett. B 829 (2022) 137066
- *"Measurements of differential cross-sections in top-quark pair events with a high transverse momentum top quark and limits on beyond the Standard Model contributions to top-quark pair production with the ATLAS detector at root s=13 TeV"*, ATLAS Collab., J. High Energy Phys. 6 (2022) 063
- *"A search for an unexpected asymmetry in the production of e(+)mu(-) and e(-)mu(+) pairs in proton-proton collisions recorded by the ATLAS detector at root s=13 TeV"*, ATLAS Collab., Phys. Lett. B 830 (2022) 137106
- *"Two-particle Bose-Einstein correlations in pp collisions at root s=13 TeV measured with the ATLAS detector at the LHC"*, ATLAS Collab., Eur. Phys. J. C 82 (2022) 608

- *"Search for long-lived charginos based on a disappearing-track signature using 136 fb(-1) of pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 606
- *"Constraints on Higgs boson properties using WW*(→ e nu mu nu)jj production in 36.1 fb(-1) of root s=13 TeV pp collisions with the ATLAS detector"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 622
- *"Measurements of the Higgs boson inclusive and differential fiducial cross-sections in the diphoton decay channel with pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, J. High Energy Phys. 8 (2022) 027
- *"Observation of WWW Production in pp Collisions at p=13 TeV with the ATLAS Detector ffi s"*, ATLAS Collaboration, Phys. Rev. Lett. 129 (2022) 061803
- *"Modelling and computational improvements to the simulation of single vector-boson plus jet processes for the ATLAS experiment"*, ATLAS Collaboration, J. High Energy Phys. 8 (2022) 089
- *"Study of B-c(+) → J/psi D-s(+) and B-c(+)→ J/psi D-s*(+)decays in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, J. High Energy Phys. 8 (2022) 087
- *"Search for invisible Higgs-boson decays in events with vector-boson fusion signatures using 139 fb(-1) of proton-proton data recorded by the ATLAS experiment"*, ATLAS Collaboration, J. High Energy Phys. 8 (2022) 104
- *"Search for events with a pair of displaced vertices from long-lived neutral particles decaying into hadronic jets in the ATLAS muon spectrometer in pp collisions at root s=13 TeV"*, ATLAS Collaboration, Phys. Rev. D 106 (2022) 032005
- *"Measurements of jet observables sensitive to b-quark fragmentation in (tt)over-bar events at the LHC with the ATLAS detector"*, ATLAS Collaboration, Phys. Rev. D 106 (2022) 032008
- *"Direct constraint on the Higgs-charm coupling from a search for Higgs boson decays into charm quarks with the ATLAS detector"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 717
- *"Measurements of Higgs boson production cross-sections in the H →tau(+) tau(-) decay channel in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, J. High Energy Phys. 8 (2022) 175
- *"Search for Higgs boson pair production in the two bottom quarks plus two photons final state in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Phys. Rev. D 106 (2022) 052001
- *"Search for type-III seesaw heavy leptons in leptonic final states in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Eur. Phys. J. C 82 (2022) 988
- *"Measurement of the polarisation of single top quarks and antiquarks produced in the t-channel at root s=13 TeV and bounds on the tWb dipole operator from the ATLAS experiment"*, ATLAS Collaboration, J. High Energy Phys. 11 (2022) 40

9 Articles in international journals (with internal review by the team)

- *"Strong constraints on jet quenching in centrality-dependent p +Pb collisions at 5.02 TeV from ATLAS"*, ATLAS Collaboration (H. Santos et al.), arXiv:2206.01138
- *"Search for heavy resonances decaying into a Z or W boson and a Higgs boson in final states with leptons and b -jets in 139 ~fb − 1 of p p collisions at √ s = 13 TeV with the ATLAS detector"*, ATLAS Collaboration (H. Santos et al.), arXiv:2207.00230
- *"Searches for exclusive Higgs and Z boson decays into a vector quarkonium state and a photon using 139 fb − 1 of ATLAS √ s = 13 TeV proton − proton collision data"*, ATLAS Collaboration (H. Santos et al.), arXiv:2208.03122
- *"Measurements of observables sensitive to colour reconnection in t ¯ t events with the ATLAS detector at √ s = 13 TeV"*, ATLAS Collaboration (H. Santos et al.), arXiv:2209.07874
- *"Search for heavy resonances decaying into a Z or W boson and a Higgs boson in final states with leptons and b-jets in 139 fb^{-1} of pp collisions at s√=13 TeV with the ATLAS detector"*, ATLAS Collaboration, JHEP, CERN-EP-2022-115
- *"Search for resonant WZ→ℓνℓ'ℓ' production in proton−proton collisions at s√=13 TeV with the ATLAS detector"*, ATLAS Collaboration, EPJC, CERN-EP-2022-093
- *"A search for new resonances in multiple final states with a high transverse momentum Z boson in s√=13 TeV pp collisions with the ATLAS detector"*, ATLAS Collaboration, JHEP, CERN-EP-2022-180
- *"Search for Higgs boson pair production in association with a vector boson in pp collisions at s√= 13 TeV with the ATLAS detector"*, ATLAS Collaboration, EPJC, CERN-EP-2022-159
- *"A search for heavy Higgs bosons decaying into vector bosons in same-sign two-lepton final states in pp collisions at s√=13 TeV with the ATLAS detector"*, ATLAS Collaboration, JHEP, CERN-EP-2022-187

5 International Conference Proceedings

- *"GPU acceleration of the ATLAS calorimeter clustering algorithm"*, N. Fernades on behalf of the ATLAS Collaboration, 2023 J. Phys.: Conf. Ser. 2438 012044.
- *"Deep Learning for the Classification of Quenched Jets"*, Rute Pedro, Proceedings of the Particles and Nuclei International Conference 2021, PoS(PANIC2021)241
- *"Collective dynamics of heavy ion collisions in ATLAS"*, H. Santos, on behalf of the ATLAS Collaboration, SciPost Phys. Proc. 10, 034 (2022)
- *"Searches for Dark Matter with the ATLAS Detector"*, Rute Pedro on behalf of the ATLAS Collaboration, Proceedings of the 14th International Conference on Identification of Dark Matter
- *"Searches for top FCNC interactions with the ATLAS detector"*, Filipe Veloso on behalf of the ATLAS collaboration, Rencontres de Moriond 2022: Proceedings of the ElectroWeak Session, La Thuile, March 12-19 2022

4 Collaboration notes with internal referee

- *"Probing the CP nature of the top-Higgs Yukawa coupling in ttH and tH events with H→bb using the ATLAS detector at the LHC"*, Ana Luísa Carvalho, Emanuel Gouveia, Luis Coelho, Ricardo Gonçalo, António Onofre, ATLAS-CONF-2022-016

- *"Combination of searches for heavy resonances using 139 fb^{-1} of proton–proton collision data at √s = 13 TeV with the ATLAS detector"*, I. Ochoa et al. (ATLAS Collaboration), ATLAS-CONF-2022-028
- *"Search for invisible particles produced in association with single top quarks in proton-proton collisions at sqrt(s)=13 TeV with the ATLAS detector"*, ATLAS Collaboration, ATLAS-CONF-2022-036
- *"Anomaly detection search for new resonances decaying into a Higgs boson and a generic new particle X in hadronic final states using √s = 13 TeV pp collisions with the ATLAS detector"*, I. Ochoa et al. (ATLAS Collaboration), ATLAS-CONF-2022-045

3 LIP Students Notes

- *"Anomaly Detection in all hadronic boosted final states"*, Junda Tong, LIP-STUDENTS-22-02
- *"Search for New Phenomena in the Top quark sector using Anomaly Detection"*, Inês Pinto, Joan Kladnik, LIP-STUDENTS-22-14
- *"Upgrade of the ATLAS Tile Calorimeter High Voltage System"*, Tiago Prates da Costa, LIP-STUDENTS-22-24

Presentations

10 Oral presentations in international conferences

- Filipe Veloso: *"Searches of top FCNC interactions with the ATLAS detector"*, 2022-03-13, Moriond EW 2022, La Thuile, Italy
- Ana Luísa Carvalho: *"Measurements of Higgs boson production in association with top quarks at the ALTAS experiment"*, 2022-05-16, 10th Edition of the Large Hadron Collider Physics Conference (LHCP2022), Taipei University (online)
- Nuno Castro: *"Rare production and decay processes in the top quark sector"*, 2022-05-19, 10th conference on Large Hadron Collider Physics - LHCP 2022, online
- Abideh Jafari, Eleni Vryonidou, Nuno Castro: *"Report from the LHC EFT WG"*, 2022-06-15, LHC TOP WG general workshop, CERN / online
- Helena Santos, on behalf of the ATLAS and CMS Collaborations: *"ATLAS and CMS results on heavy-flavour jets"*, 2022-07-16, HF-WINC2022,
- Rute Pedro: *"Searches for Dark Matter with the ATLAS Detector"*, 2022-07-21, 14th International Conference on Identification of Dark Matter, Viena
- Beatriz Pinheiro Pereira: *"Performance of the ATLAS/LHC Tile Calorimeter plastic scintillators"*, 2022-09-22, 16th International Conference on Scintillating Materials & their Applications, Santa Fé - USA
- Patricia Conde: *"Higgs Physics results at ATLAS"*, 2022-09-29, Workshop on Multi-Higgs Models, IST, Lisbon, Portugal
- Ricardo Barrué: *"Fisher Information and simulation-based inference in searches for CP-violating EFT components in the HWW interaction via leptonic WH production"*, 2022-11-10, Higgs conference 2022, Pisa, Italy
- Helena Santos, on behalf of the ATLAS Collaboration: *"Recent results from heavy ion collisions with ATLAS"*, 2022-12-04, Discovery Physics at the LHC, South Africa

1 Poster presentation(s) in international conference(s)

- Ana Luísa Carvalho: *"Between even and odd: probing the CP-nature of the Higgs-Top Yukawa coupling"*, 2022-07-08, International Conference on High Energy Physics (ICHEP 2022), Bologna, Italy

6 Oral presentations in national or international meetings

- P. Conde Muíño, J. J. Gaardhøje, A. Haungs, K. Henjes-Kunst, N. Kalantar-Nayestanaki, F. Moglia, T. Montarulli, N. Pastrone, J. Wambach: *"Diversity in Collaborations"*, 2022-05-05, JENAS 2022, Second Joint Seminar APPEC/ECFA/NuPECC, Madrid, Spain
- Inês Ochoa: *"Challenges of Anomaly Detection with LHC data"*, 2022-05-25, PHYSTAT-Anomalies
- Inês Ochoa: *"ATLAS Operations and Analyses"*, 2022-07-08, Jornadas LIP 2022, Coimbra
- Patricia Conde: *"Prospects in Particle Physics"*, 2022-09-09, XLIX International Meeting on Fundamental Physics, Benasque (Spain)
- N. Fernandes, P. Conde, N. Roma, P. Tomás: *"Accelerating the ATLAS Trigger System with Graphical Processing Units"*, 2022-10-11, ATLAS Week - Early Career Scientists Forum, Lisbon
- Ana Luísa Carvalho: *"Commissioning of the ATLAS trigger system for Run 3"*, 2022-11-29, LHCC meeting, CERN

6 Poster presentations in national or international meetings

- Ricardo Gonçalo: *"ATLAS Upgrades"*, 2022-07-08, Jornadas LIP 2022, Coimbra
- Beatriz Pinheiro Pereira: *"ATLAS and FCC Scintillator Detectors"*, 2022-07-09, Jornadas LIP 2022, Coimbra
- B. Pereira R. Pedro and P. Muíño: *"Radiation damage of Tile Calorimeter optical components"*, 2022-10-11, ATLAS Week, Lisbon
- R. Barrué, P. Conde Muíño: *"The ATLAS jet trigger in Run 3"*, 2022-10-11, ATLAS Week, Lisbon, Lisbon
- Ana Luísa Carvalho: *"ATLAS Forward Proton detector trigger development for Run 3"*, 2022-10-11, ATLAS Week, Lisbon
- Gabriela Pinhão: *"The ATLAS Publication Tracking System"*, 2022-10-11, ATLAS Week, Lisbon

1 Presentation(s) in national conference(s)

- Nuno Castro: *"CERN and particle physics: challenges and opportunities"*, 2022-05-16, Encontro Ciência 2022, Lisboa

7 Oral presentations in advanced training events

- Rute Pedro: *"Higgs Physics 3,"*, 2022-04-11, Course on Physics at the LHC, LIP Lisbon
- Patricia Conde: *"Higgs boson: experimental picture"*, 2022-04-21, Invited class in the master course on the Standard Model, IST, Universidade de Lisboa, Lisbon
- Inês Ochoa: *"Physics Beyond the SM with the LHC"*, 2022-05-10, 7th Lisbon mini-school on particle and astroparticle physics

- Rute Pedro: *"Tutorial "Hands-On Higgs""*, 2022-05-14, Mini-School on Particle and AstroParticle Physics, LIP, Lisbon
- Rute Pedro: *"ATLAS Open Data"*, 2022-05-18, Doctoral Course on Particle Physics Techniques, IST, Universidade de Lisboa, Lisbon
- B. Pereira F. Alcaso and R. Barrué: *"ROOT basic Tutorial"*, 2022-07-12, LIP Internship Programme Tutorial Week 2022, Online
- Rute Pedro: *"Python Tools in High Energy Physics"*, 2022-07-13, LIP Internship 2022, LIP Lisbon

3 Student presentations in advanced training events

- Rudnei Machado: *"Radiation Hardness of Plastic Scintillating Material for Scintillator Calorimeters"*, 2022-07-06, 7th LIP/IDPASC student workshop, Coimbra
- N. Fernandes, P. Conde, N. Roma, P. Tomás: *"Accelerating the ATLAS Trigger system with Graphical Processing Units"*, 2022-07-06, IDPASC PhD Students Workshop, Coimbra
- B. Pereira R. Pedro and P. Muíño: *"Radiation damage of the optical components in Scintillator Detectors: from the ATLAS/LHC Tile Calorimeter to future experiments"*, 2022-07-07, 7th LIP/IDPASC student workshop, Coimbra

1 Seminar(s)

- Patricia Conde: *"The Higgs boson, 10 years after discovery"*, 2022-12-14, Departamento de Física, Faculdade de Ciências, Universidade de Lisboa

3 Outreach seminars

- Rute Pedro: *"À Caça das Partículas"*, 2022-03-04, IPPOG Particle Physics MasterClasses, UTAD, Vila Real
- Patricia Conde: *"À procura de partículas no CERN"*, 2022-03-26, IPPOG Particle Physics Masterclasses, IST, ULisboa, Lisbon
- Patricia Conde: *"Para além do bosão de Higgs"*, 2022-06-01, Micropalestras sobre supertemas, IST, Lisboa, Lisbon

Theses

7 PhD

- Ana Luísa Carvalho: *"Study of the CP properties of the Higgs coupling to top quarks with ATLAS at the LHC."*, 2019-01-12, (ongoing), IST, Supervisor(s): Ricardo Gonçalo, Patricia Conde
- Ricardo Barrué: *"Study of the Spin/CP properties of the Higgs coupling to W-bosons with ATLAS at the LHC"*, 2020-09-01, (ongoing), IST, Supervisor(s): Patricia Conde, Rui Santos
- Maura Teixeira: *"Searching for dark matter with the ATLAS detector using unconventional signatures"*, 2021-01-01, (ongoing), UMinho, Supervisor(s): Nuno Castro, Miguel Romão
- Luis Coelho: *" Exploring the electroweak vacuum with di-Higgs production at the LHC ATLAS experiment"*, 2021-05-01, (ongoing), UC, Supervisor(s): Ricardo Gonçalo, Filipe Veloso
- Beatriz Pinheiro Pereira: *"Radiation Damage of Optical Components in Scintillator Detectors: from the ATLAS/LHC Tile Calorimeter to Future Experiments"*, 2021-02-01, (ongoing), IST, Supervisor(s): Rute Pedro, Patricia Conde
- Rudnei Machado: *"Radiation Damage of the TileCal Optics components at the High Luminosity LHC phase"*, 2021-09-01, (ongoing), IST, Supervisor(s): Rute Pedro, Patricia Conde
- Nuno Fernandes: *"Accelerating the ATLAS Trigger system with Graphical Processing Units"*, 2022-01-01, (ongoing), IST, Supervisor(s): Patricia Conde

8 Master

- Patrícia Ferreira: *"Machine Learning for Anomaly Detection in the Atlas Trigger at the LHC"*, 2021-09-10 / 2023-02-24, (finished), UC, Supervisor(s): Ricardo Gonçalo, Miguel Romão
- Rúben Inácio: *"Exploiting Graph Neural Networks for jet identification in LHC experiments"*, 2022-07-06, (ongoing), IST, Supervisor(s): Inês Ochoa, Patricia Conde
- Maria Miguel: *"Interlock electronics for the high Granularity Timing Detector od the ATLAS"*, 2022-10-15, (ongoing), UC, Supervisor(s): Ricardo Gonçalo
- António Caramelo: *"High Voltage filters for the High Granularity Timing Detector of the ATLAS Experiment"*, 2022-10-15, (ongoing), UC, Supervisor(s): Ricardo Gonçalo
- Pedro Lagarelhos: *"Prospects for the HL-LHC of the measurement of the top quark couplings in the ttbar semileptonic channel"*, 2018-09-16, (ongoing), IST, Supervisor(s): António Onofre
- Catarina Pereira: *"Performance of the TileCal High Voltage Upgrade System"*, 2019-09-16, (ongoing), FCUL, Supervisor(s): Agostinho Gomes, Guiomar Evans
- Rui Fernandes Marques: *"Controlo Digital e Nova Electrónica para o Banco de Testes para o Sistema de Alta Tensão dos Fotomultiplicadores do Tilecal"*, 2016-09-12, (ongoing), FCUL, Supervisor(s): Agostinho Gomes, Guiomar Evans
- João Pedro Pires: *"Deep Neural Netwoers in Experimental Data Analyses"*, 2021-11-08, (ongoing), FCUL, Supervisor(s): Helena Santos

CMS

Collaboration in the CMS experiment at CERN

Principal Investigator:
Michele Gallinaro (100)

7 ***Researcher(s):***
Alessio Boletti (100), Cristóvão Silva (100), Jonathan Hollar (100), João Varela (100), Nuno Leonardo (65), Pietro Faccioli (25), Tahereh Niknejad (100)

2 ***Technician(s):***
José Carlos Silva (100), Rui Pereira da Silva (50)

6 ***PhD Student(s):***
Diogo de Bastos (100), Giacomo Da Molin (42), Giovanni Marozzo (17), Johan Wulff (34), Mariana Araújo (35), Matteo Pisano (100)

2 ***Master Student(s):***
Henrique Legoinha (100), Simão Costa (25)

9 ***Undergraduated Student(s) and Trainee(s):***
Alexandre André, Beatriz Amorim, Jean Luo, Leonardo Rodrigues, Luisa Roesler, Manuel Abreu, Manuel Afonso Ratola, Pedro Batista, Sónia Paulo D'Azevedo

8 ***External collaborator(s):***
Carlos Lourenço, Giles Strong, João Seixas, Luis Ferramacho, Miguel Silveira, Pedrame Bargassa, Pedro Ferreira da Silva, Ricardo Bugalho

Total FTE:
12.9 (PhD 6.9)

Articles in international journals:	**6** Direct contribution **55** Indirect contribution
Notes:	**5** Internal notes **3** Collaboration notes **4** LIP Students notes
International conferences:	**7** Oral presentations **2** Poster **5** Proceedings
National conferences:	**1** Poster
Nat.& Internat. meetings:	**4** Oral presentations
Collaboration meetings:	**32** Oral presentations
Advanced Training Events:	**24** Oral presentations **2** Student presentations
Seminars:	**3** Seminars **2** Outreach seminar
Articles in Outreach Journals:	**1** Article in Outreach Journal

Executive summary

The Compact Muon Solenoid (CMS) experiment at the LHC is a major scientific endeavour, and the research at the LHC is central to the quest for the fundamental physics laws of nature. LIP is member of the CMS Collaboration at the LHC since its creation in 1992.

LIP had a leading role in the design and construction of important components of the CMS detector, namely the data acquisition system of the ECAL sub-detector used for the measurement of electrons and photons and the trigger system that performs the online selection of the interesting collisions. Since the LHC start-up in 2010, LIP made major contributions to the CMS physics program in particular: the discovery and characterization of a Higgs boson; measurements of the top quark properties; the first observation of the rare Bs to dimuon decay, studies of B and Y mesons in pp and heavy ion collisions; measurement of the chi and upsilon polarizations; searches for a charged Higgs, a top squark, and for Dark Matter; search for exclusive processes. The former group PI João Varela served as Deputy Spokesperson of the CMS Collaboration in 2012-13.

The group contributed to the Phase-I Upgrade of the experiment by building and installing new High-Speed Optical Links (oSLB-oRM) that interface the ECAL electronics to the trigger system. The CMS experiment took data in Run 2 (2015-2018) at an energy of 13 TeV, and it started taking data again in 2023 after a period of maintenance and upgrades. During the long-shutdown (LS2), the group has been involved in the preparation of the PPS (Precision Proton Spectrometer) and the ECAL detectors.

The LIP group is leading the development of the new forward Precision Proton Spectrometer (PPS). PPS demonstrated -for the first time- the feasibility of operating a near-beam proton spectrometer at high luminosity on a regular basis. A member of the group is presently serving as PPS Project Deputy Coordinator.

In the high-luminosity phase of the LHC physics program starting in 2029, the accelerator will provide an additional integrated luminosity of 3000 fb^{-1} over 10 years of operation. The group participates in the construction of a new timing detector and in the upgrade of the barrel and endcap calorimeters. The group is responsible for the design and construction of the readout system of the Barrel Timing Layer (BTL), including a high-performance TOF ASIC for time measurement. In collaboration with industry, LIP provides a high-performance ADC ASIC for the ECAL front-end electronics resistant to radiation. The CMS upgrade also includes the complete replacement of the Endcap calorimeters with a new high-granularity sampling calorimeter. LIP collaborates with industry by supplying a high-current low voltage regulator (LVR) resistant to radiation for the High-Granularity Calorimeter (HGCAL) front-end system.

The group is actively involved and contributing to the physics analyses in the areas of Top quark, Higgs boson, B mesons, SUSY, quarkonia, heavy ions, and PPS physics. A member of the LIP group has coordinated the CMS B Physics group in 2014-2016. Two former members of the group, now with CERN, have also coordinated in 2015-16 the CMS Higgs and Top physics groups.

It is worth noting that in the most recent (July 2019) institutional evaluation performed by an international review panel under the initiative of FCT, LIP received the highest quality grade (Excellent). The contribution of the CMS group was explicitly recognized in the panel's report: “The CMS group, while small in size, is really outstanding and world-class”.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
João Varela (Michelle Gallinaro)	FCT	200.000 €	2021-09-16 to 2023-09-15	CERN/FIS-INS/0029/2021 / Collaboration in the Phase 2 Upgrade of the CMS experiment at CERN
Michele Gallinaro (Nuno Leonardo)	FCT	185.000 €	2021-11-01 to 2023-10-31	CERN/FIS-PAR/0005/2021 / Collaboration in the operation and physics data analysis at the CMS experiment at CERN
Jonathan Hollar (Michelle Gallinaro)	FCT	248.366 €	2022-01-01 to 2024-12-31	PTDC/FIS-PAR/1214/2021 / Precision timining with forward protons at the HL-LHC

CMS

Overview

The activities of the group cover the following areas:

1) Proton-proton physics:

The objective is to fully exploit the discovery opportunities offered by the LHC high energy and luminosity. The activity is organized in different domains, namely Higgs Physics, Top Quark Physics, B Physics, Quarkonia, SUSY, and physics in central exclusive production (PPS). Each domain is led by a senior physicist and integrates researchers and students.

2) Heavy-ion physics:

The ultimate objective is the study of the quark-gluon plasma and the strong interaction, taking advantage of the collisions of heavy-ion beams at the LHC.

3) CMS Upgrades:

The objective of this program is to contribute with R&D of new detector technologies for the Upgrade of the CMS experiment in view of its future operation at the HL-LHC.

4) Experiment operation and maintenance:

The LIP/CMS group has people based at CERN that are required for the normal maintenance and operation of the ECAL and PPS detectors. The group has a dedicated electronics lab installed in the CERN campus used for R&D and maintenance work.

Team organization

The group coordinator is Michele Gallinaro. He has 30 years research experience both in the US (SLAC and Fermilab) and at CERN. The deputy coordinators are Nuno Leonardo (20 years of research experience at Fermilab and CERN) and Jonathan Hollar (20 years of research experience at SLAC and CERN).

Group activities are organized in the three complementary funded projects listed in the table in the previous page:

- Collaboration in the operation and physics data analysis at the CMS experiment at CERN. PI: M. Gallinaro, co-PI: N. Leonardo.
- Collaboration in the Phase 2 Upgrade of the CMS experiment at CERN. PI: Joao Varela (40 years of research experience at CERN) co-PI: M. Gallinaro.
- Precision timing with forward protons at the HL-LHC. PI: J. Hollar. Co-PI: M. Gallinaro.

Other present coordination positions in the LIP/CMS group are:

- PI operation and physics data analysis – M.Gallinaro

- Co-PI operation and physics data analysis – N.Leonardo

- PI Phase 2 upgrades - J.Varela

- Co-PI Phase 2 upgrades - M.Gallinaro

- Physics Analysis Coordinators - M.Gallinaro, N.Leonardo, J.Hollar, J.Seixas, P.Faccioli

- Detector coordinators: PPS (J.Hollar), ECAL (J.C.Silva)

- Computing link person - J. Wulff and D.Bastos

Group members have presently the following coordination positions in the CMS collaboration structure:

- PPS Coordinator (Level-1), since 2021 (J.Hollar)

- ECAL Electronics Coordinator (Level-2), since 2011 (J.C.Silva)

- B-Physics Exotica and Rare Decays (ERD) coordinator (Level-3), since 2021 (A.Boletti)

- MTD/BTL electronics systems coordinator, since 2018 (J.Varela)

- MTD/BTL front-end electronics coordinator, since 2018 (J. C. Silva)

- MTD/BTL front-end ASIC coordinator of the, 2020-2021 (T. Niknejad)

LIP group members participate in the following CMS structures:

- CMS Collaboration Board (M.Gallinaro, J.Varela)

- CMS Finance Board (J.Varela)

- CMS Management and Executive Boards (J.Hollar)

- CMS Publication Board (N.Leonardo, P.Faccioli)

- ECAL Executive Board (J.C.Silva)

- ECAL, MTD and HGCAL Institution Boards (J.Varela)

- PPS Institution Board (M.Gallinaro)

- MTD Steering Committee (J.Varela)

The group has a general weekly meeting and a dedicated upgrade weekly meeting. Comprehensive reviews of each sub-area of physics analyses or upgrade R&D take place every 3 months. LIP/CMS seminars for presentation of the main activities and results are held regularly at LIP.

Group members are regularly selected to participate in Analysis Review Committees and Detector Review Committees. Group members convene the following weekly meetings of the CMS Collaboration: PPS general meeting, BTL electronics meeting, B-Physics ERD meeting.

Assessment of the past year: objectives vs. achievements

There were no major deviations from the goals set for 2022.

Within the CMS experimental program, the LIP/CMS group made major scientific contributions in 2022 in the following areas:

1) Proton-proton physics

a) Top quark physics

Group members (A. Toldaiev, M. Gallinaro) had a leading role in the first Run 2 results on the measurement of the top quark pair production cross section in the dilepton channel including a tau lepton. The work was the subject of the PhD thesis of A. Toldaiev who graduated with the highest classification in Ocober 2020. Lepton Flavor Universality (LFU) studies are pursued in the leptonic decays of the W bosons in top quark events (G. Da Molin, M. Gallinaro) in collaboration with colleagues at IIT Madras.

In a similar final state, a study of vector boson scattering (VBS) processes including a tau lepton using the full Run 2 data (M. Magherini, M. Gallinaro) is pursued in collaboration with colleagues at Univ. of Perugia.

b) Search for SUSY

Group members (D. Bastos, C. Cruz e Silva, P. Bargassa) had a leading role in the search for the 4-body decay of the lightest scalar top (stop) in the Run 2 data. The analysis with the full Run 2 sample has been approved for publication and the first results presented at the SUSY 2022 conference.

c) Search for double Higgs production

Di-Higgs (HH) production search in the "tautaubb" final state in the full Run 2 data is performed using advanced machine learning analysis techniques. Dedicated regression and classification studies were pursued. The analysis was published. Projections of the expected sensitivity developed for the Yellow Report were updated for different HL-LHC conditions. The activity, carried out in the framework of the EU Marie-Curie network AMVA4NewPhysics (G. Strong, M. Gallinaro), was the subject of the PhD thesis of G. Strong who graduated with the highest classification in December 2020. The studies for a resonant HH production are being pursued (J. Wulff, M. Gallinaro).

d) Search for Dark Matter

Members of the LIP/CMS group (M. Gallinaro) pursued a search for Dark Matter produced in association with a Higgs boson. The search, developed in collaboration with colleagues from Bari Polytechnic, was published. The search with the full Run 2 data is being finalized.

e) Flavour anomalies and heavy flavour

The study of rare decays remains a priority. The interest is reinforced by the large datasets and by the so-called flavor anomalies (FA). The group carried out measurements of b-quark production and fragmentation, a crucial ingredient for the measurement of rare B decays. These have been originally pursued in pp 13 TeV data (B. Alves, N. Leonardo), and more recently with the 2017 dataset collected at 5 TeV (M. Faria, N.Leonardo). Another important decay realizing the b→sll transition is B→K*μμ. The group is carrying out the analyses of the angular observables and rates (M. Faria, A. Boletti, N. Leonardo) with the full Run 2 data. CMS internal review of the results is ongoing. Involvement of LIP internship students (M. André, R. Jafari, R. Pozzi; S. D'Azevedo, M. Abreu) contributed to extensions of the work, e.g. exploring the CMS parked data.

f) Quarkonia polarization

The group (M. Araujo, P. Faccioli, J. Seixas), together with C. Lourenço (CERN) and T. Madlener (HEPHY) performed the first measurement of the polarizations of χc1 and χc2 states. Precise measurements of the polarizations of several quarkonium states are being pursued using the larger Run 2 data samples, which will have an important impact in the understanding of quarkonium production.

g) Search for exclusive two-photon production using the PPS spectrometer

Group members (J. Hollar, K. Shchelina) led the first analysis of dilepton production via two-photon interactions with tagged forward protons using the PPS detector. Currently, group members are pursuing related analyses of two-photon production of tau lepton pairs (M. Pisano, M. Gallinaro, J. Hollar), W and Z boson pairs (K. Shchelina, J. Hollar) and top quark pairs (M. Pisano, M. Gallinaro, J. Hollar) using PPS data. The studies of exclusive top quark pair production and exclusive VV (V=W,Z) production were approved and presented at recent international conferences by group members. The paper of the exclusive WW/ZZ production was submitted for publication.

2) Heavy-ion physics

B mesons as novel probes of QGP

The group is bringing unique expertise of B physics into the heavy ion realm, and it has been playing a leading role in the investigation of B mesons in PbPb data.

First observation of the Bs meson in nuclear collisions and measurement of the Bs/B+ production ratio was published (2022) in collaboration with colleagues at MIT. It led to successful theses, MSc at IST (J. Silva, 2019), PhD at MIT (Z. Shi, 2021), with leading systematic uncertainties determined by undergraduate students (A. Pardal, J. Gonçalves). A group member (N. Leonardo) wrote the observation paper.

The measurement of the nuclear modification factors RAA was developed (H. Legoinha, M. Faria, N. Leonardo) and entered CMS internal review. The measurement of B mesons production cross-sections at 5 TeV pp collisions (S. Costa, H. Legoinha, N. Leonardo) is ongoing. Work performed by LIP internship students (S. Costa, J. Luo) and summarized in an internal note is part of the documentation for internal analysis review.

3) Experiment operation and maintenance

a) Physics objects development:

LIP members pursued the participation in the activities of POGs (Physics Object Groups) in the validation of forward proton alignment and reconstruction efficiency (M. Pisano), and PPS high-level trigger (M. Araújo). A member of the LIP/CMS group (J. Hollar) led the preparation of the reference paper describing key features of the proton reconstruction procedure, efficiency and reconstruction that was submitted for publication. Tag-and-probe tools for muon measurements with CMS open data were contributed (N. Leonardo with non-LIP CMS members).

b) PPS commissioning and operation:

Under the leadership of a LIP member serving as PPS Project Manager (J. Varela), PPS collected over 100fb^{-1} of data in Run2. The group had leading roles in the PPS DAQ system (J. Hollar) and the Timing detectors (M. Gallinaro). LIP made major contributions to the timing detector electronics, online software, and detector operations. Since 2021, a LIP member serves as Project Manager (J.Hollar). Members of the group are actively involved in physics analyses using PPS data (M. Pisano, M. Gallinaro, J.Hollar), and had leading roles in the first PPS physics publication.

c) ECAL: A member of the group (J.C. Silva) maintained the ECAL trigger and DAQ system.

d) Computing: A member of the group (D. Bastos) served as LIP/CMS interface with the LIP Tier2 group.

e) General: The group provided central shifts and EPR (Experimental Physics Responsibilities) work according to the rules of the CMS collaboration.

4) Phase-II Upgrades (HL-LHC)

The R&D towards the Phase-II upgrade carried out by the group is organized in four areas:

a) R&D for the Barrel Timing Layer: Development of the front-end readout system of the timing detector (LYSO crystals and SiPMs) based on a fast-timing TOF ASIC provided by Portuguese industry (LIP's full responsibility).

b) R&D in the ECAL front-end readout system: Development of the new ECAL readout system based on a new 160 MB/s low power ADC ASIC provided by Portuguese industry (CEA Saclay, INFN-Torino and LIP responsibility).

c) R&D on the High Granularity Calorimeter: Development of algorithms for the HGCAL L1 trigger. Support to the development of low voltage regulator (LVR) ASIC resistant to radiation provided by the Portuguese industry.

d) R&D for the PPS timing detectors: Develop LGAD sensors and associated electronics for use as timing detectors in the HL-LHC PPS upgrade, resistant to highly non-uniform radiation and with good (~40-50 ps) time resolution.

a) Timing Detector

a1) Development Front-end ASIC TOFHIR2

The Barrel Timing Layer (BTL) is a thin standalone detector in the region between the outer tracker and the ECAL based on LYSO:Ce crystals read-out with silicon photomultipliers (SiPMs) for precise timing of minimum ionizing particles. The full BTL detector has about 330,000 readout channels. The LIP group is responsible for the design and construction of the BTL readout system. Dedicated ASIC electronics (TOFHIR) will be used to readout the SiPM arrays. The TOFHIR ASIC is being developed in the framework of the Collaboration Agreement KN436/EP between LIP and CERN. The microelectronics design of the TOFHIR circuits is sub-contracted to the Portuguese company PETsys Electronics. The development is proceeding according to the plan.

A first version of the chip (TOFHIR1) was implemented in 2019. A new design (TOFHIR2) with increased radiation tolerance was pursued in 2020. The chip is one of the most complex front-end chips designed for the LHC experiments. The new chip (TOFHIR2A) pioneered a dedicated circuit to mitigate the increase of noise in the SiPMs due to radiation (DCR cancelation). An advanced version the DCR cancelation circuit was implemented in TOFHIR2X together with other improvements. TOFHIR2X was fabricated in the first half of 2021 and successfully tested in July-September 2021. The performance matches well the predictions. The final version of the ASIC (TOFHIR2B) was submitted for fabrication in November 2021. It implements the option of increased amplifier gain to cope with the progressive loss of signal yield due to radiation during the detector lifetime, besides other improvements.

The validation of TOFHIR2B coupled to sensor modules was performed at LIP in the first half of 2022. Tests of sensor modules coupled to TOFHIR2X performed with test beams at CERN in October 2021 and June 2022 showed that the timing performance measured in beam is well reproduced in the lab. The validation of the resilience against single event transients of TOFHIR2B was done at the Heavy Ion Facility in Louvain in April and June 2022. A few minor bugs in the digital logic of TOFHIR2B were identified and corrected.

A CMS Review of the TOFHIR2 ASIC took place in October 2022. The review report stated that the chip is ready for mass production. About 15'000 chips have been ordered in November 2022 and are expected in March 2023.

a2) Development of the front-end readout system

The readout of sensor modules is implemented in the Front-End (FE) board. LIP has the responsibility for the design, production, and testing of the FE Boards. One member of the LIP group is responsible for coordinating the development of the whole BTL readout system.

LIP designed and produced different electronics boards. For ASIC characterization, we developed the TOFHIR2 Test Board (T2TB), as well as adapter boards to the PETsys SiPM readout system used extensively by LIP and other groups in the MTD project. A few were produced and tested for distribution to the detector Assembly Centres in Milano, Virginia and Caltech, and were shipped to CERN for integration in the second version readout unit (RU). In parallel, prototype detector modules based on TOFHIR2X were evaluated with proton beams at the CERN SPS in October 2021 and in June 2022.

a3) Integration of large-scale prototypes of the BTL detector

The BTL detector is formed by 72 trays, each with a length of 250 cm, width of 20 cm and thickness of 4 cm. Each tray is formed by six RU mounted on both sides of the cooling plate. Several large-scale prototyping activities are foreseen to fully validate the BTL before starting the final construction. Together with other groups (INFN Milano, Princeton, Northeastern University, Caltech, CEA Saclay, Novosibirsk), the LIP group is collaborating in the construction and characterization of large-scale prototypes of the BTL detector.

The integration and characterization of the second version of the RU based on TOFHIR2 started at the end 2021 at CERN and pursued in 2022. The measurements were completed recently showing excellent performance.

b) ECAL Readout System

In the context of the full replacement of the electronics of the ECAL, LIP delivered a high-performance ADC ASIC for the ECAL front-end electronics resistant to radiation. The Portuguese industry was contracted to supply a high-performance ADC IP block featuring 12-bit, 160 MS/s and low power consumption. The ADC design was supplied and integrated by the INFN-Torino group in a CMOS 65 nm chip that implements additional digital logic and data transmission (LiTE-DTU chip).

c) High Granularity Calorimeter

For the HGCAL project, in collaboration with industry, LIP supplied a high-current low voltage regulator (LVR) resistant to radiation for the frontend system. The development of the powering scheme of the HGCAL is challenging given the large number of channels, the large power dissipation, and the large radiation dose and particle fluence in the endcap region. The Portuguese industry concluded in 2020 the development of a low voltage regulator LVR ASICs resistant to radiation with the performance required by HGCAL. The evaluation of the LVR prototype chips was performed at CERN in 2021 with good results.

d) Precision Proton Spectrometer

A new near-beam proton spectrometer at the HL-LHC will include timing and tracking detectors. The large number of "pile-up" interactions foreseen at the HL-LHC (up to 200) makes it necessary to measure the longitudinal coordinate of the vertex via time-of-flight; sensors with a single plane time resolution of 40−50 ps are adequate. For the choice of the detector technology, synergies with the ongoing developments for the Phase-II upgrade of the central pixel system and the forward MIP timing detector are considered. The LIP group, in collaboration with other groups (Fermilab, Torino, Zurich), is pursuing R&D studies of LGAD silicon sensors and associated electronics for timing measurements.

5) Outreach & advanced training

Group members take part in outreach activities for high school and university students (MasterClasses, CERN visits, student sessions at LIP and IST). A group member (N. Leonardo) coordinated the LIP summer internship program and served as co-coordinator of advanced training at LIP. Group members have been actively contributing to the Teachers School in Portuguese Language at CERN.

Lines of work and objectives for next year

The LIP/CMS group activities in 2023 will closely follow the research program of last year. The group plans to participate in the following areas of physics analysis and detectors activities:

Task 1: Physics analysis

1) Higgs physics

a) Search for di-Higgs events in resonant and non-resonant modes in the di-tau bbar final state;

b) Search for H (and Z) rare decays to quarkonium, a potential means for constraining and accessing the Yukawa couplings to the light quarks, a challenge for the future LHC runs.

2) Electroweak physics

a) Finalize measurement of the quartic gauge coupling γγWW using PPS;

b) Search for exclusive processes by tagging a leading forward proton using PPS.

3) B physics
Exploration of rare decays and flavour anomalies.

4) New physics in top like events

Studies of lepton flavor universality in top quark events, and vector boson scattering processes with tau leptons in final state.

5) SUSY physics

Finalize search for SUSY top squark in four-body decays.

6) Quarkonia

Precise measurements of the polarizations of the J/psi and other quarkonium states.

7) Heavy-ion physics

Explore heavy flavor signals as QGP probes with LHC ion and reference pp datasets.

Task 2: R&D Phase-II Upgrade

1) R&D in the Barrel Timing Layer (BTL)

Finalization of the BTL ASIC TOFHiR2 in radiation tolerant CMOS 130 nm technology of TSMC (TOFHIR2). Tests of the final version (TOFHIR2C) and preparation for the wafer production and BGA encapsulation for the detector, development of the front-end readout system, integration of large-scale BTL prototypes.

2) R&D in the ECAL frontend readout system

Characterization of a new version of the LiTE-DTU chip, including tests of the ECAL front-end chain (collaboration with INFN Torino and CEA Saclay).

3) R&D on the High Granularity Calorimeter (HGCAL)

Follow-up of the development by Portuguese industry of the low voltage regulator (LVR) resistant to radiation.

4) R&D on the PPS timing detector upgrade for HL-LHC

Explore LGAD sensors and associated electronics for use as timing detectors in the HL-LHC PPS upgrade, resistant to highly non-uniform radiation and with good (~40-50ps) time resolution.

Task 3: Experiment operation and maintenance

1) ECAL: Maintenance of the ECAL trigger and data acquisition system.

2) PPS: Operation and maintenance of the new pixel and timing detectors and DAQ system of the PPS project.

3) Physics objects development: Participation in the development and validation of the tau lepton and proton reconstruction in the framework of the corresponding Tau and Proton Physics Object Groups (POGs).

4) Computing: LIP/CMS interface with the LIP Tier2.

5) General: The LIP group will provide central shifts and EPR work according to the rules of the CMS collaboration.

Medium-term (3-5 years) prospects

In the period 2023-27 the LIP/CMS group plans to keep the participation in the CMS experiment at the same high level of quality, responsibility, and visibility. We plan to purse the physics analyses of different topics profiting from the large amount of data expected until the end of Run 3. The objective is to fully exploit the discovery opportunities offered by the LHC. The activity is organized in main physics domains, namely Higgs boson, Top quark, B mesons, Quarkonia, SUSY, PPS, and Heavy Ions, spanning from the search for new particles and phenomena beyond the standard Model (SM) to the precise measurements of the SM properties.

The group was responsible for the upgrade of the data acquisition system of the Precision Proton Spectrometer (PPS) in view of the Run 3 data-taking, and will now contribute to the maintenance and operation of the PPS and Electromagnetic Calorimeter (ECAL) sub-detectors. A member of the group was the main editor of the Letter of Intent that proposes to install a new PPS-like detector system for the HL-LHC to extend the sensitivity to detection of rare processes and possible discoveries through the study of anomalous couplings or direct new particle production.

Finally, the group will be strongly involved in the CMS Phase-II Upgrade for the HL-LHC, developing microelectronics for the readout systems of the MTD, ECAL, and HGCAL, in collaboration with the Portuguese industry, and taking the leadership in the development of the MTD readout system.

Physics

The SM does not provide answers to many fundamental questions in particle physics. Tiny deviations from the SM due to interactions with other forms of matter, including Dark Matter, could answer some very fundamental questions. The detailed study of the 125 GeV Higgs is a scientific imperative that must be pursued to a much higher level of statistical precision than it is available today. Until the end of Run 3, the CMS experiment expects to collect up to 300 $^{fb-1}$. The LIP/CMS group plans to contribute to the Higgs studies as well as to searches for new physics with these new data.

Detector Operation and Upgrades

Precision Proton Spectrometer (PPS)

With the LHC Run 2 dataset, all measurements using PPS are limited by statistics. Therefore, the detectors were upgraded and continue to operate in Run 3 to exploit the high luminosity delivered by the LHC.

During Long Shutdown 2, all detector packages were removed from the LHC tunnel, and have been replaced with new or refurbished detectors.

Among the major changes, the timing detectors in Run 3 are based on double-diamond layers, and a second timing Roman Pot station was added. The new PPS pixel tracking stations are instrumented with piezoelectric motors, to allow mitigation of radiation damage via vertical movements of the sensors.
The baseline PPS timing readout is based on HPTDC mezzanine cards, for which LIP has led the design and production. LIP will also contribute to the testing and characterization of the timing readout chain, as well as the online software for both the timing and pixel tracking detectors, and the development of new high-level triggers.

Electromagnetic Calorimeter

In the CMS operations in the period 2023-2025, the group plans to continue to be responsible for the operation and maintenance of the ECAL Data Acquisition and Trigger hardware.

HL-LHC Phase-II Upgrades

In the High-Luminosity phase of the LHC physics program, the accelerator will provide CMS with an additional integrated luminosity of 3000 fb^{-1} over 10 years of operation, starting in 2029. To meet the experimental challenges of this unprecedented proton-proton luminosity, the CMS collaboration will undertake the Phase-II upgrade program to maintain the excellent performance of the detector.

The LIP participation in the CMS Phase-II Upgrades is concentrated in the MIP Timing Detector and in the ECAL and HGCAL Calorimeters and PPS detector. The generic goals of these upgrades are the following:

1. MIP Timing Detector: addition of a timing layer in front of the Calorimeters for precise timing measurement of all charged particles;

2. Electromagnetic Calorimeter: full replacement of the ECAL barrel electronics;

3. High Granularity Calorimeter: complete replacement of the Endcap calorimeters with a new high-granularity sampling calorimeter;

4. Precision Proton Spectrometer: Participation in the upgrade of the PPS for the HL-LHC started with the LoI and will continue with the preparation of the Technical Design Report addressing specific physics and detector R&D studies. Explore LGAD sensors and associated electronics for use as timing detectors in the HL-LHC PPS upgrade.

The LIP/CMS group participation in the Phase-II Upgrade reflects a close match and synergies between the historical role and technological expertise of the LIP group in the CMS experiment, the new opportunities offered by the Upgrade Projects, and the recognized world-wide leadership of Portuguese high-tech microelectronics companies in the domains relevant for the project.

SWOT Analysis

Strengths

Group well integrated in the Collaboration. Several senior physicists with long experience in CMS and strong impact. Several coordination positions, including the leadership of the PPS sub-detector, and the leading role in several physics analyses. Leadership in different areas of the front-end readout systems of the Phase II Upgrade.

Weaknesses

Difficulty in attracting foreign researchers to Portugal. Difficult and lengthy evaluation process to award National fellowships and/or long-term positions to outstanding candidates in HEP.

Opportunities

Opportunity for a strong participation of Portuguese industry, world leader in segments of microelectronics intelectual property (IP) market, in the CMS Phase II Upgrade for HL-LHC.

Threats

Unclear career prospects for senior physicists with key responsibilities in the group and in the collaboration.

CMS

Publications

6 Articles in international journals (with direct contribution from team)

- *"Vector Boson Scattering Processes: Status and Prospects"*, M. Gallinaro et al., Rev.Phys. 8 (2022) 100071
- *"Observation of Bs0 mesons and measurement of the Bs0/B+ yield ratio in PbPb collisions at 5.02 TeV"*, CMS Collaboration, Phys. Lett. B 829 (2022) 137062
- *"Search for nonresonant Higgs boson pair production in final state with two bottom quarks and two tau leptons in proton-proton collisions at 13 TeV"*, CMS Collaboration, CMS-HIG-20-010
- *"A portrait of the Higgs boson by the CMS experiment ten years after the discovery"*, CMS collaboration, Nature 607 (2022) 7917, 60-68
- *"Search for high-mass exclusive gammagamma→ WW and gammagamma→ ZZ production in proton-proton collisions at sqrt(s) = 13 TeV"*, CMS and TOTEM Collaborations, arXiv:2211.16320
- *"Proton reconstruction with the CMS-TOTEM Precision Proton Spectrometer"*, CMS and TOTEM Collaborations, arXiv:2210.05854

55 Articles in international journals (with indirect contribution from team)

- *"Evidence for X(3872) in Pb-Pb Collisions and Studies of its Prompt Production at root s(NN)=5.02 TeV"*, CMS Collaboration, Phys. Rev. Lett. 128 (2022) 032001
- *"Measurement of double-parton scattering in inclusive production of four jets with low transverse momentum in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 1 (2022) 177
- *"Study of quark and gluon jet substructure in Z plus jet and dijet events from pp collisions"*, CMS Collaboration, J. High Energy Phys. 1 (2022) 188
- *"Search for long-lived particles decaying to leptons with large impact parameter in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, Eur. Phys. J. C 82 (2022) 153
- *"Fragmentation of jets containing a prompt J/psi meson in PbPb and pp collisions at root s(NN)=5.02 TeV"*, CMS Collaboration, Phys. Lett. B 825 (2022) 136842
- *"Inclusive and differential cross section measurements of single top quark production in association with a Z boson in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 2 (2022) 107
- *"Measurement and QCD analysis of double-differential inclusive jet cross sections in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 2 (2022) 142
- *"Search for flavor-changing neutral current interactions of the top quark and the Higgs boson decaying to a bottom quark-antiquark pair at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 2 (2022) 169
- *"Measurement of the Inclusive and Differential Higgs Boson Production Cross Sections in the Decay Mode to a Pair of tau Leptons in pp Collisions at root s=13 TeV"*, CMS Collaboration, Phys. Rev. Lett. 128 (2022) 081805
- *"Search for heavy resonances decaying to WW, WZ, or WH boson pairs in a final state consisting of a lepton and a large-radius jet in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, Phys. Rev. D 105 (2022) 032008
- *"A new calibration method for charm jet identification validated with proton-proton collision events at root s=13 TeV"*, CMS Collaboration, J. Instrum. 17 (2022) P03014
- *"Search for strongly interacting massive particles generating trackless jets in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, Eur. Phys. J. C 82 (2022) 213
- *"Measurement of W-+/-gamma differential cross sections in proton-proton collisions at root s=13 TeV and effective field theory constraints"*, CMS Collaboration, Phys. Rev. D 105 (2022) 052003
- *"Search for W\gamma resonances in proton-proton collisions at vs=13 TeV using hadronic decays of Lorentz-boosted W bosons"*, CMS Collaboration, Phys. Lett. B 826 (2022) 136888
- *"Search for long-lived particles produced in association with a Z boson in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 3 (2022) 160
- *"Using Z Boson Events to Study Parton-Medium Interactions in Pb-Pb Collisions"*, CMS Collaboration, Phys. Rev. Lett. 128 (2022) 122301
- *"Study of dijet events with large rapidity separation in proton-proton collisions at root s=2.76 TeV"*, CMS Collaboration, J. High Energy Phys. 3 (2022) 189
- *"Search for low-mass dilepton resonances in Higgs boson decays to four-lepton final states in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, Eur. Phys. J. C 82 (2022) 290
- *"Search for a heavy resonance decaying into a top quark and a W boson in the lepton plus jets final state at root s=13 TeV"*, A. Tumasyan et al., J. High Energy Phys. 4 (2022) 048
- *"Search for a right-handed W boson and a heavy neutrino in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 4 (2022) 047
- *"Search for long-lived particles decaying into muon pairs in proton-proton collisions at root s=13 TeV collected with a dedicated high-rate data stream"*, A. Tumasyan et al., J. High Energy Phys. 4 (2022) 062
- *"Measurement of the top quark mass with lepton+jets final states using pp collisions at root s = 13TeV (vol 78, 891, 2018)"*, CMS Collaborat, Eur. Phys. J. C 82 (2022) 323
- *"Search for heavy resonances decaying to ZZ or ZW and axion-like particles mediating nonresonant ZZ or ZH production at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 4 (2022) 087
- *"Search for supersymmetry in final states with two or three soft leptons and missing transverse momentum in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 4 (2022) 091

- *"Measurement of exclusive Upsilon photoproduction from protons in pPb collisions at root s(NN) = 5.02 TeV (vol 79, 277, 2019)"*, CMS Collaboration, Eur. Phys. J. C 82 (2022) 343
- *"Search for electroweak production of charginos and neutralinos in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 4 (2022) 147
- *"Measurement of the inclusive t(t)over-bar production cross section in proton-proton collisions at root s=5.02 TeV"*, CMS Collaboration, J. High Energy Phys. 4 (2022) 144
- *"Precision measurement of the W boson decay branching fractions in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, Phys. Rev. D 105 (2022) 072008
- *"Search for new physics in dijet angular distributions using proton-proton collisions at root s = 13TeV and constraints on dark matter and other models (vol 78, 789, 2018)"*, CMS Collaboration, Eur. Phys. J. C 82 (2022) 379
- *"Search for heavy resonances decaying to a pair of Lorentz-boosted Higgs bosons in final states with leptons and a bottom quark pair at root s=13 TeV"*, A. Tumasyan et al., J. High Energy Phys. 5 (2022) 005
- *"Search for higgsinos decaying to two Higgs bosons and missing transverse momentum in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 5 (2022) 014
- *"Measurement of the inclusive and differential t(t)over-bar gamma cross sections in the dilepton channel and effective field theory interpretation in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 5 (2022) 091
- *"Search for single production of a vector-like T quark decaying to a top quark and a Z boson in the final state with jets and missing transverse momentum at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 5 (2022) 093
- *"Search for invisible decays of the Higgs boson produced via vector boson fusion in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, Phys. Rev. D 105 (2022) 092007
- *"Observation of B-0 → psi(2S)K-S(0)pi(+)pi(-) and B-s(0)→ psi(2S)K-S(0) decays"*, CMS Collaboration, Eur. Phys. J. C 82 (2022) 499
- *"Measurement of the production cross section for Z plus b jets in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, Phys. Rev. D 105 (2022) 092014
- *"Analysis of the CP structure of the Yukawa coupling between the Higgs boson and tau leptons in proton-proton collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 6 (2022) 012
- *"Inclusive nonresonant multilepton probes of new phenomena at root s=13 TeV"*, CMS Collaboration, Phys. Rev. D 105 (2022) 112007
- *"Search for charged-lepton flavor violation in top quark production and decay in pp collisions at root s=13 TeV"*, CMS Collaboration, J. High Energy Phys. 6 (2022) 082
- *"Observation of the B-c(+) Meson in Pb-Pb and pp Collisions at root s(NN)=5.02 TeV and Measurement of its Nuclear Modification Factor"*, CMS Collaboration, Phys. Rev. Lett. 128 (2022) 252301
- *"Search for resonant production of strongly coupled dark matter in proton-proton collisions at 13 TeV"*, CMS Collaboration, J. High Energy Phys. 6 (2022) 156
- *"A Full Current-Mode Timing Circuit with Dark Noise Suppression for the CERN CMS Experiment"*, E. Albuquerque, R. Bugalho, L. B. Oliveira, T. Niknejad, J. C. Silva, Alessio Boletti, J. Varela, ESSCIRC 2022- IEEE 48TH EUROPEAN SOLID STATE CIRCUITS CONFERENCE (ESSCIRC) ISBN 978-1-6654-8494-7 (2022) 177-180
- *"Identification of hadronic tau lepton decays using a deep neural network"*, CMS Collaboration, J. Instrum. 17 (2022) P07023
- *"Probing Charm Quark Dynamics via Multiparticle Correlations in Pb-Pb Collisions at root s(NN)=5.02 TeV"*, CMS Collaboration / CMS Collaboration, Phys. Rev. Lett. 129 (2022) 022001
- *"Measurement of the inclusive and differential WZ production cross sections, polarization angles, and triple gauge couplings in pp collisions at root s=13 TeV"*, CMS Collab., J. High Energy Phys. 7 (2022) 032
- *"Search for resonances decaying to three W bosons in the hadronic final state in proton-proton collisions at root s=13 TeV"*, CMS Collab., Phys. Rev. D 106 (2022) 012002
- *"Search for Resonances Decaying to Three W Bosons in Proton-Proton Collisions at root s=13 TeV"*, CMS Collab, Phys. Rev. Lett. 129 (2022) 021802
- *"Search for new physics in the lepton plus missing transverse momentum final state in proton-proton collisions at root s=13 TeV"*, CMS Collab., J. High Energy Phys. 7 (2022) 067
- *"Search for Flavor-Changing Neutral Current Interactions of the Top Quark and Higgs Boson in Final States with Two Photons in Proton-Proton Collisions at root s=13 TeV"*, CMS Collab., Phys. Rev. Lett. 129 (2022) 032001
- *"Search for long-lived heavy neutral leptons with displaced vertices in proton-proton collisions at root s=13 TeV"*, CMS Collab., J. High Energy Phys. 7 (2022) 081
- *"Measurement of the Drell-Yan forward-backward asymmetry at high dilepton masses in proton-proton collisions at root s=13 TeV"*, CMS Collab., J. High Energy Phys. 8 (2022) 063
- *"Search for Higgs Boson Pair Production in the Four b Quark Final State in Proton-Proton Collisions at root s=13 TeV"*, CMS Collab., Phys. Rev. Lett. 129 (2022) 081802
- *"Search for high-mass resonances decaying to a jet and a Lorentz-boosted resonance in proton-proton collisions at root s=13 TeV"*, CMS Collab., Phys. Lett. B 832 (2022) 137263
- *"Search for a W' boson decaying to a vector-like quark and a top or bottom quark in the all-jets final state at root s=13 TeV"*, CMS Collab., J. High Energy Phys. 9 (2022) 088
- *"Measurement of the Higgs boson width and evidence of its off-shell contributions to ZZ production"*, CMS Collaboration, Nat. Phys. 18 (2022) 1329-+

8 Articles in international journals (with internal review by the team)

- *"Observation of triple J/psi meson production in proton-proton collisions at sroot = 13 TeV"*, CMS Collaboration, arXiv:2111.05370
- *"Search for rare Higgs boson decays with mesons at the HL-LHC"*, CMS Collaboration, CMS-FTR-21-009
- *"Observation of B0 → psi(2S)K0Spi+pi- and B0S → psi(2S)K0S decays"*, CMS Collaboration, Eur. Phys. J. C 82 (2022) 499

- *"Search for Higgs boson pairs decaying to WWWW, WWtata, and tatatata in proton-proton collisions at 13 TeV"*, CMS Collaboration, CMS-HIG-21-002
- *"Measurement of the production cross section of a W boson in association with a charm quark in proton-proton collisions at 13 TeV"*, CMS Collaboration, CMS-SMP-21-005
- *"Search for pair-produced vector-like leptons in final states with third-generation leptons and at least three b quark jets in proton-proton collisions at 13 TeV"*, CMS Collaboration, CMS-B2G-21-004
- *"Measurement of the dependence of the hadron production fraction ratio fs/fu on B meson kinematic variables in proton-proton collisions at sroot = 13 TeV"*, CMS Collaboration, CMS-BPH-21-001, CERN-EP-2022-248
- *"Observation of tau lepton pair production in ultraperipheral lead-lead collisions at sqrt(sNN) = 5.02 TeV"*, CMS Collaboration, arXiv:2206.05192

5 International Conference Proceedings

- *"Results with the TOFHIR2X revision of the front-end ASIC of the CMS MTD Barrel Timing Layer"*, T. Niknejad et al., 2021 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), Piscataway, NJ, USA, 2021
- *"Snowmass 2021 White Paper Instrumentation Frontier 05 -- White Paper 1: MPGDs: Recent advances and current R&D"*, M. Gallinaro et al., arXiv:2203.06562 - Contribution to Snowmass
- *"Lepton universality tests and searches for charged lepton violation at CMS"*, M. Gallinaro (on behalf of the CMS collaboration), PoS NuFact2021 (2022) 131
- *"Precise timing and recent advancements with segmented anode PICOSEC Micromegas prototypes"*, I. Manthos et al., JINST 17 (2022) 10, C10009
- *"Looking forward: Photon induced processes with tagged protons at the CMS experiment"*, Michele Gallinaro, proceedings for "Diffraction and Low-x", Corigliano Calabro, Italy, 24-30 Sept. 2022

5 Internal Notes

- *"Combination of the searches for exclusive production of top quark pairs in the dilepton and lepton+jets channels"*, M.Pisano, M.Gallinaro, J.Hollar, CMS AN-2021/038
- *"Search for central exclusive production of tau pairs in proton-proton collisions at 13 TeV"*, M.Pisano, M.Gallinaro, J.Hollar, CMS AN-2022/010
- *"Search for dark matter produced in association with a Higgs boson decaying to four leptons using the full Run II data"*, M.Gallinaro et al., CMS AN-2020/013
- *"Vector Boson Scattering measurement of same-sign W boson pairs with hadronic taus in the final state"*, M.Gallinaro et al., CMS AN-2021/042
- *"Measurement of the polarizations of JPsi and psi(2S) mesons promptly and non-promptly produced in pp collisions at 13 TeV"*, Mariana Araujo, Pietro Faccioli , Carlos Lourenco et al., CMS AN-2021/003

3 Collaboration notes with internal referee

- *"Search for top squarks decaying via the four-body mode in single-lepton final states from Run 2 of the LHC"*, CMS Collaboration, CMS-SUS-21-003
- *"Search for central exclusive production of top quark pairs in proton-proton collisions at 13 TeV with tagged protons"*, CMS and TOTEM collaborations, CMS-PAS-TOP-21-007
- *"The evolution and performance of the CMS detector at the CERN LHC"*, CMS Collaboration, CMS-PRF-21-001

4 LIP Students Notes

- *"Colliding photons at the High Luminosity LHC with the CMS"*, T. Urruzola (Supervisors J. Hollar, M. Pitt), CERN-STUDENTS-Note-2022-158
- *"Study of central and exclusive production of tau-tau pairs at LHC"*, Alexandre André, Pedro Batista, LIP-STUDENTS-22-06
- *"Measurement of B+ and B0 s meson cross sections in pp collisions at the LHC"*, Simão Costa, Jean Luo, LIP-STUDENTS-22-10
- *"High-precision timing detectors for the HL-LHC"*, Beatriz Amorim, LIP-STUDENTS-22-18

1 Article(s) in Outreach Journal(s)

- *"CMS looks forward to new physics with PPS"*, M. Arneodo, M. Pitt, E. Robutti, K. Shchelina, et al., CERN Courier Volume 62, Number 5

Presentations

7 Oral presentations in international conferences

- Diogo de Bastos: *"Searches for top squarks in compressed scenarios"*, 2022-06-29, The XXIX International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY-2022), Ioannina, Greece
- A. Boletti: *"Results from angular analyses of B-meson decays in CMS"*, 2022-07-09, ICHEP 2022, Bologna, Italy
- M. Gallinaro: *"Vector Boson Scattering: Status and Prospects"*, 2022-07-20, Snowmass Summer Meeting 2022, Seattle, USA
- M. Gallinaro: *"The Standard Model Higgs and beyond"*, 2022-09-01, Workshop on "Multi-Higgs models, IST, Lisbon
- Alessio Boletti: *"Results with the TOFHIR2B revision of the front-end ASIC of the CMS MTD Barrel Timing Layer"*, 2022-09-20, TWEPP 2022, Bergen, Norway
- M. Gallinaro: *"Photon-induced processes with tagged protons at the CMS experiment"*, 2022-09-28, International workshop on "Diffraction and Low-x, Corigliano Calabro, Italy
- T. Niknejad: *"Radiation tolerance measurement of the TOFHIR2 chip for the CMS barrel timing detector"*, 2022-11-08, IEEE Nuclear Science Symposium, Milano, Italy

1 Poster in national conference

- Giacomo Da Molin: *"Study of b- and c-jets identification for Higgs coupling measurements at the Muon Collider"*, 2022-09-14, 108 SIF Annual Congress, Milan, Italy

2 Poster presentation(s) in international conference(s)

- M. Pisano: *"Central exclusive production of tar t pairs at CMS and TOTEM"*, 2022-11-29, CERN - Posters@LHCC: Students' Poster Session at the 2022 November LHCC meeting, CERN
- M. Pisano: *"Central exclusive production processes at the LHC"*, 2022-11-14, IST - PhD Open Days, Lisbon, Portugal

4 Oral presentations in national or international meetings

- J. Hollar, S. Giani: *"PPS for Phase2: current situation"*, 2022-05-31, Meeting with LHCC referees-LHCC150, CERN
- M. Pisano: *"Study of central exclusive production processes within the CMS collaboration"*, 2022-07-06, Jornadas LIP 2022, Coimbra
- J. Hollar, C. da Cruz e Silva: *"CMS Detectors and Upgrades"*, 2022-07-08, Jornadas LIP 2022, Coimbra,
- M. Gallinaro: *"The CMS group"*, 2022-07-08, Jornadas LIP 2022, Coimbra

24 Oral presentations in advanced training events

- Nuno Leonardo: *"Flavour Anomalies at LHC "*, 2022-05-13, 7th Lisbon mini-school on Particle and Astroparticle Physics, Oeiras
- Nuno Leonardo: *"Introduction to LHC Physics"*, 2022-07-12, 6th LIP Internship Program, Lisbon
- J. Hollar: *"Standard Model Processes"*, 2022-03-14, IDPASC Course on Physics at the LHC, Lisbon (Online)
- M. Gallinaro: *"Top quark: Introduction"*, 2022-03-21, Course on Physics at the LHC 2022, LIP, Lisbon
- M. Gallinaro: *"Top quark: Properties and beyond"*, 2022-03-23, Course on Physics at the LHC 2022, LIP, Lisbon
- M. Gallinaro: *"Higgs boson: Beyond the SM searches"*, 2022-04-13, Course on Physics at the LHC 2022, LIP, Lisbon
- M. Gallinaro: *"Exotic processes and Dark Matter"*, 2022-05-04, Course on Physics at the LHC 2022, LIP, Lisbon
- M. Gallinaro: *"Flavour Anomalies and BSM"*, 2022-05-11, Course on Physics at the LHC 2022, LIP, Lisbon
- M. Gallinaro: *"The experimental program at the LHC"*, 2022-05-17, Doctorate Course at University of Perugia (XXXVII ciclo), Perugia, Italy
- M. Gallinaro: *"Probing the Standard Model at the LHC"*, 2022-05-19, Doctorate Course at University of Perugia (XXXVII ciclo), Perugia, Italy
- M. Gallinaro: *"The Top quark"*, 2022-05-20, Doctorate Course at University of Perugia (XXXVII ciclo), Perugia, Italy
- M. Gallinaro: *"Top quarks and beyond"*, 2022-05-24, Doctorate Course at University of Perugia (XXXVII ciclo), Perugia, Italy
- M. Gallinaro: *"The Standard Model Higgs and beyond"*, 2022-05-24, Doctorate Course at University of Perugia (XXXVII ciclo), Perugia, Italy
- M. Gallinaro: *"Exotica and Dark Matter searches"*, 2022-05-26, Doctorate Course at University of Perugia (XXXVII ciclo), Perugia, Italy
- C. da Cruz e Silva: *"Tutoring of students in ISOTDAQ"*, 2022-06-13, ISOTDAQ 2022, Catania, Italy
- M. Pisano: *"Introduction to central exclusive production events"*, 2022-07-01, LIP - Estágios de verão, Lisbon, Portugal
- N.Leonardo, G.Soares, A.Boletti: *"Data analysis and fitting tutorial"*, 2022-07-14, 6th LIP Internship Program, LIP
- A. Boletti: *"CMS detector activities"*, 2022-08-23, CMS Summer Student meeting, LIP
- M. Pisano: *"The data taking and the DAQ system of CMS"*, 2022-11-14, LIP/IST - Cadeira LFUI supervision, Lisbon, Portugal
- M. Pisano: *"The central exclusive production of tau-tau pairs at the LHC"*, 2022-12-05, LIP/IST - Cadeira LFUI supervision, Lisbon, Portugal
- M. Pisano: *"Multivariate analysis techniques"*, 2022-12-12, LIP/IST - Cadeira LFUI supervision, Lisbon, Portugal
- M. Gallinaro: *"Probing the Standard Model at the LHC: The Higgs boson and beyond"*, 2022-05-13, 7th mini-school on Particle and Astroparticle Physics, Oeiras, Portugal
- N.Leonardo: *"Flavour Anomalies at LHC"*, 2022-05-13, 7th mini-school on Particle and Astroparticle Physics, Oeiras
- M. Pisano: *"The standard model and the LHC experiments"*, 2022-07-20, LIP - High school summer students formation, Lisbon, Portugal

2 Student presentations in advanced training events

- Michele Gallinaro: *"The Precision Proton Spectrometer at the LHC"*2022-04-08, Seminar, Univ. of Cyprus
- Jonathan Hollar: *"New CMS Results on top quarks (and other things) from photon collisions"*, 2022-10-06, LIP-Lisboa Seminar, LIP, Lisbon (zoom)

3 Seminar(s)

- M. Gallinaro: *"CERN's Large Hadron Collider: The Big Bang machine"*, 2022-07-01, A desafiar os limites da ciencia e tecnologia, IST, Lisbon
- Michele Gallinaro: *"The Precision Proton Spectrometer at the LHC"*, 2022-04-08, Seminar, Univ. of Cyprus
- Jonathan Hollar: *"New CMS Results on top quarks (and other things) from photon collisions"*, 2022-10-06, LIP-Lisboa Seminar, LIP, Lisbon (zoom), ptext

2 Outreach seminar(s)

- M. Pisano: *"The standard model and the LHC experiments"*, 2022-07-20, LIP - High school summer students formation, Lisbon, Portugal
- M. Gallinaro: *"CERN's Large Hadron Collider: The Big Bang machine"*, 2022-07-01, A desafiar os limites da ciencia e tecnologia, IST, Lisbon

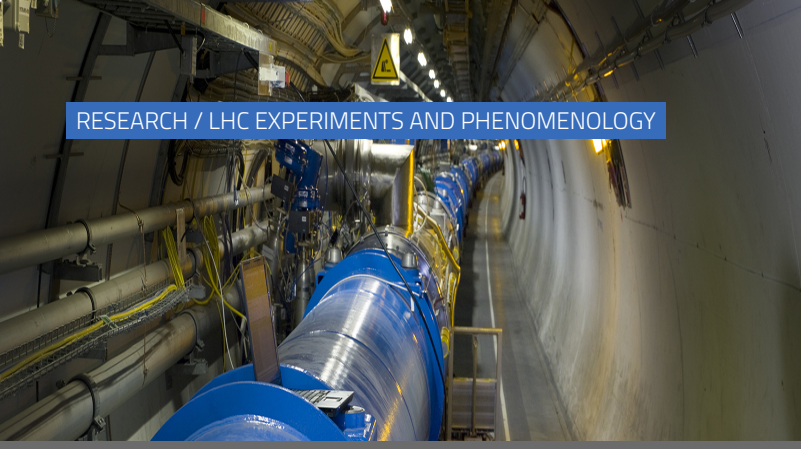
Theses

5 PhD

- Diogo de Bastos: *"Search for the supersymmetric stop quark in the CMS experiment"*, 2017-11-19, (ongoing), IST, Supervisor(s): Pedrame Bargassa, João Varela
- Matteo Pisano: *"Search for new physics in exclusive processes at the Large Hadron Collider"*, 2020-07-10, (ongoing), IST, Supervisor(s): Michele Gallinaro, Jonathan Hollar
- Johan Wulff: *"Timing Detectors and Measurements of Higgs Boson Properties"*, 2022-05-15, (ongoing), IST, Supervisor(s): Michele Gallinaro, Jonathan Hollar
- Giacomo Da Molin: *"Study of lepton universality in top quarks pairs events"*, 2022-09-01, (ongoing), IST, Supervisor(s): Michele Gallinaro
- Giovanni Marozzo: *"Search for New Physics in gauge boson scattering with the CMS experiment at the Large Hadron Colliderics in gauge boson scattering with the CMS experiment at the Large Hadron Collider"*, (ongoing), IST, Supervisor(s): Jonathan Hollar, Michele Gallinaro

2 Master

- Henrique Legoinha: *"Probing the properties of the plasma of quarks and gluons with heavy flavour"*, 2021-10-01, (ongoing), IST, Supervisor(s): Nuno Leonardo
- Simão Costa: *"Quark hadronization with B mesons at the LHC"*, 2022-09-15, (ongoing), IST, Supervisor(s): Nuno Leonardo



RESEARCH / LHC EXPERIMENTS AND PHENOMENOLOGY

PHENO

Phenomenology

Principal Investigator:
Guilherme Milhano (85)

13 ***Researcher(s):***
António Onofre (60), Catarina Espírito Santo (20), Filipe Veloso (20), Grigorios Chachamis (88), Helmut Wolters (7), João Nuno Pires (72), Liliana Apolinário (85), Miguel Fiolhais (60), Miguel Romão (56), Nuno Castro (17), Pablo Rodriguez (100), Pietro Faccioli (37), Ruben Conceição (7)

2 ***Technician(s):***
Henrique Carvalho (30), João Carlos Silva (17)

9 ***PhD Student(s):***
André Cordeiro (100), Dario Vaccaro (50), Esteban Chalbaud (100), Fernando Souza (100), João Arruda Gonçalves (100), João Martins da Silva (100), Maria Ramos (8), Mariana Araújo (66), Susana Santos (100)

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7 ***Undergraduated Student(s) and Trainee(s):***
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16 ***External collaborator(s):***
Agustin Sabio Vera, Andrea Ferroglia, Carlos Lourenço, Carlota Casas, Francisco del Aguila Giménez, Fábio Dominguez, Guilherme Guedes, José Santiago Perez, João Lourenço Barata, João Seixas, Juan Antonio Aguilar Saavedra, Korinna Zapp, Mikael Chala, Osvaldo Freitas, Rui Santos, Solange Nunes

Total FTE:
23.1 (PhD 7.7)

Articles in international journals:	**11** Direct contribution
Notes:	**1** LIP Students note
International conferences:	**3** Oral presentations
	1 Poster
	4 Proceedings
Nat.& Internat. meetings:	**3** Oral presentations
Seminars:	**4** Seminars
Completed theses:	**1** PhD
	6 MScs

Executive summary

LIP's Phenomenology group conducts research bridging theory and experiment in collider physics in the areas of QCD and New Physics Searches. While independent, its research is centred around areas in which LIP has active experimental activities through its participation in several collaborations at the LHC, and aims to identify areas in which LIP's broader programme may evolve in the future (e.g: the FCC). Its purpose is to strengthen the impact of the overall LIP programme through the provision of excellent directed phenomenological research. Due to its nature, it addresses several topical issues also covered by LIP's experimental groups allowing for synergies to develop. Such include jet quenching phenomenological studies, whose analysis receive contribution from LIP's ATLAS group, top physics analysis, phenomenological interpretations of quarkonium production, whose measurements are done by LIP's CMS group, New physics searches and jet quenching studies conducted jointly with the Competence Center on Simulation and Big Data and QCD precision studies also pursued by the LIP's FCC group. Moreover, the group collaborates with the LIP group in the Pierre Auger Observatory on quark-gluon plasma related studies.

The group members have maintained their excellent publication record and high international visibility. International recognition of the group has been manifest in expressions of interest by researchers at all levels of seniority to join the group.

The group's commitment to train a new generation of researchers, and thus guarantee the long term sustainability of Phenomenology research in the country, has resulted in a very large increase in students (internships, MSc and PhD) choosing to further their training within the group.

The group continues its sustainable path of development and relevance both within and outside LIP.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Guilherme Milhano	EU	188.500 €	2019-06-01 to 2023-11-30	COST 824093 - STRONG-2020 / The strong interaction at the frontier of knowledge:fundamental research and applications
Guilherme Milhano	EU	399.062 €	2019-10-01 to 2025-09-30	ERC Grant 835105 - YoctoLHC / Yoctosecond imaging of QCD collectivity using jet observables
Guilherme Milhano Liliana Apolinário	FCT	90.000 €	2020-07-01 to 2022-06-30	CERN/FIS-PAR/0024/2019 / Bridging Theory and Experiment: Collider Phenomenology
Pietro Faccioli	FCT	20.000 €	2020-09-01 to 2022-08-31	CERN/FIS-PAR/0010/2019 / Methods for Understanding Strong Interactions with Quarkonia
António Onofre (Miguel Fiolhais)	FCT	45.000 €	2021-11-15 to 2023-11-14	CERN/FIS-PAR/0037/2021 / TopHiggsPheno - Pheno studies of top quark and Higgs boson physics at the LHC
Liliana Apolinário (Carlota Casas)	FCT	49.464 €	2021-12-01 to 2023-05-31	EXPL/FIS-PAR/0905/2021 / Unveiling the space-time structure of jets
Grigorios Chachamis (João Nuno Pires)	FCT	49.922 €	2022-01-17 to 2023-07-16	EXPL/FIS-PAR/1195/2021 / The Strong force and multiparticle dynamics at hadron colliders
Guilherme Milhano (Liliana Apolinário)	FCT	80.000 €	2022-07-01 to 2024-06-30	CERN/FIS-PAR/0032/2021 / THbridgeEXP-II Bridging theory and experiment: Collider phenomenology (II)

Pheno

Overview

The group has consolidated research programmes in both QCD and New Physics Searches. The scope of our QCD work has expanded over the years, encompassing at present heavy-ion phenomenology — with a focus on both the initial stages of the collision and characterization of Quark-Gluon Plasma through jet observables —, forward physics, precision collider predictions, and quarkonia studies. The group has accumulated extensive expertise in the development of event-generators and has pioneered studies for extracting the time evolution of Quark Gluon Plasma, including its formation stages, through analysis of jet properties. New Physics searches focus on top-quark, Higgs, and Dark Matter studies.

The Phenomenology group has established a close synergy with the Competence Center on Simulation and Big Data, with studies addressing both the identification of strongly quenched jets in heavy-ion collisions and putative New Physics signals in collider searches. In addition, our group explores physics opportunities in future collider facilities contributed in a close collaboration with the recently created LIP's FCC group.

The activities of the group are distributed over all the three (Lisboa, Coimbra, Minho) nodes of LIP. The group's bi-weekly remote meetings have contributed to create a healthy cross-talk environment within the group and provide an important discussion community for the increasing number of students being trained in the group. While group members enjoy freedom of focus for their work, on-going discussions have led to the identification of topical issues where complementary expertise within the group can lead to international leadership in new domains. In addition, new synergies with other LIP's group are presently being further explored, contributing to the visibility of LIP as international leader in Particle and Astroparticle Physics.

Assessment of the past year: objectives vs. achievements

The main objectives for 2022 were:

- Focus on consolidated research areas to achieve even higher international competitive level
- Increase synergy with LIP's Simulation and Big Data Competence Center
- Follow sustained growth, in particular, by attracting further students and researchers to join the group, building on current expertise

During 2022:

1) Consolidate group research areas:

- The success of our efforts in consolidating the group research areas has been demonstrated by several international leadership positions that illustrate its high international visibility. Namely, team members:
  - Act as Theory co-convener of the LHC Physics Centre Heavy-Ions Working group
  - Lead a work package, and serve in its Governing Board, in the STRONG2020 consortium
  - Have been invited to plenary talks at top conferences of the field (e.g: DIS 2022) and seminars
  - Served in the Local and Program Committee of the XXIX International Workshop on Deep-Inelastic Scattering (DIS2022, Santiago de Compostela (Spain) in May 2022
  - Serve in the International Advisory Committee of the VII International Conference on the Initial Stages of High-Energy Nuclear Collisions (Copenhagen, Denmark, July 2023)
  - Served in the Local Organising committee of the 12th International Workshop on Multiple Partonic Interactions at the LHC (MPI@LHC)
- The group has produced high-impact scientific output across the different research areas, including topical reviews on:
  - Jets and heavy-flavour as probes of the Quark-Gluon Plasma
  - Jets and Jet Substructure at Future Colliders
  - Flavour-Changing Neutral Scalar Interactions of the Top Quark
- Group members also participated in the large-scale effort to present the next-to-next-to-leading-order (NNLO) analysis of the HERA data on inclusive deep inelastic electron-proton scattering;
- Moreover, the group actively participated in the activities of Snowmass 2021 (Particle Physics Community Planning Exercise organised by the Division of Particles and Fields of the American Physical Society) and contributed in the discussions and the resulting white papers, mainly in the Energy Frontier, the Theory Frontier, the Accelerator Frontier and the Computational Frontier.

2) Increasing synergies

- Our synergy with the Simulation and Big Data Competence Center has been demonstrated by several publications and a PhD student that is jointly supervised with members from the Big Data competence center
- The synergy with cosmic ray experimental groups have been demonstrated by the jointly supervision of a MSc student with the LIP Auger group

3) Sustained growth:

- We currently have seven PhD student and several MSc students that develop their works within the group activities .

In addition, four MSc students successfully defended their theses with topics fully within the group's activities, three of them will join us for a PhD in the following year. Additionally, one PhD student also defended her thesis during 2022.

Lines of work and objectives for next year

We will continue the activities on the existing consolidated areas that have demonstrated to be competitive at international level and very successful to the laboratory. These include the core group portfolio on QCD precision physics, heavy-ions, top physics, BSM physics and Higgs.

For each of these lines of work, focus will be given to fully explore the physics potential of the upcoming phases of the LHC.

New Physics searches through BSM and Higgs analysis will be centred on data-driven/model-independent studies with machine and deep learning techniques, powered by the successful synergy with the Simulation and Big Data competence centre.

As for the **QCD precision physics and heavy-ions**, four on-going paths will be followed concurrently:

- Exploration avenue to harness the full potential of a new accelerator, with close collaboration with the FCC group at LIP; This endeavour, targeting QCD precision physics, will also benefit from the collaboration with the Simulation and Big Data competence centres as application of Machine Learning techniques will also be explored to better constrain the non-perturbative region of QCD.
- Effort to achieve better theoretical precision that can match experimental uncertainties from high-luminosity runs and future lighter ions runs; This is mostly carried within the group as it brings together the complementary expertises from the distinct members.
- A complementary synergy with the Auger group at LIP to explore the onset conditions necessary to the emergence of complexity within QCD (quark-gluon plasma formation), paving the way for future lighter-ion runs at the LHC.
- The arrival of new researcher (with a 6-year contract awarded by FCT in last year's Individual Call to Scientific Employment Stimulus) with expertise in kinetic theory will allow us to extend our studies of the initial stages of heavy ion collisions.

Finally, the group intends to continue to follow its sustained growth strategy. This involves, in particular, the continuing seek for funding dedicated to maintain the existing non-permanent members, while attracting further students and researchers to join the group, building on current expertise.

Medium-term (3-5 years) prospects

The prospects for the next 3-5 years will be centred around the following lines of action:

- Promoting a wide-scope high-quality research programme in Phenomenology, including Astroparticle Physics.
- Contributing to the shaping of LIP's evolving research programme.
- Nurture collaborations with local LIP groups that share common research interests, namely LHC, FCC and Auger groups.
- Maintaining stable structural funding.

The excellent activities developed by the current members have helped to establish the group as a centre of excellence in the areas of QCD phenomenology at high energy colliders and BSM searches. However, to fulfil its role as the phenomenology arm of LIP, the group needs to reinforce the number of researchers that can cover the overlap with the other areas of strategic and topical importance to the laboratory.

In the medium term, the group will be fully committed to have a leading role in particle physics phenomenology, with active collaborations across theory and phenomenology groups, both nationally and internationally.

SWOT Analysis

Strengths

Internationally recognised and very active research of high impact in QCD & related subjects and BSM searches; Growing number of students being trained in the group across the different research topics; Demonstrated ability to seek competitive National/European funding.

Weaknesses

Insufficient critical mass to cover phenomenological wealth of physics addressed by experimental groups at LIP; Most of the senior members still depend on national scientific temporary employment.

Opportunities

Increasing ability to attract PhD students in the framework of the PT-CERN Grants; Increasing international connections with US and Italy, while maintaining mature collaborations with centres of excellence such as CERN-TH, Santiago de Compostela, Lund, Granada, MIT.

Threats

Uncertainty in the ability to retain current precariously employed researchers and corresponding risk in demoting established activity areas within the group. Reduction of available PhD grants and consequently reduction in ability to attract students.

Pheno

Publications

11 Articles in international journals (with direct contribution from team)

- *"An experiment for electron-hadron scattering at the LHC"*, K.D. J. André et al, Eur.Phys.J.C 82 (2022) 1, 40
- *"A template method to measure the t(t)over-bar polarisation"*, J. A. Aguilar-Saavedra, M. C. N. Fiolhais, P. Martin-Ramiro, J. M. Moreno, A. Onofre, Eur. Phys. J. C 82 (2022) 134
- *"Impact of jet-production data on the next-to-next-to-leading-order determination of HERAPDF2.0 parton distributions"*, H1 Collaboration / ZEUS Collaboration, Eur. Phys. J. C 82 (2022) 243
- *"Jets and Jet Substructure at Future Colliders"*, Johan Bonilla et al., Front. Physics 10 (2022) 897719
- *"On the conformal spin dependence of the perturbative QCD vacuum singularity"*, G.~Chachamis and A.~Sabio Vera, JHEP 07 (2022) 109
- *"On the polarization of the non-prompt contribution to inclusive J/psi production in pp collisions"*, Pietro Faccioli, Carlos Lourenco, J. High Energy Phys. 10 (2022) 010
- *"NNLO interpolation grids for jet production at the LHC"*, D. Britzger, A. Gehrmann-De Ridder, T. Gehrmann, E. W. N. Glover, C. Gwenlan, A. Huss, J. Pires, K. Rabbertz, D. Savoiu, M. R. Sutton, J. Stark, Eur.Phys.J.C 82 (2022) 10, 930
- *"Improved background subtraction and a fresh look at jet sub-structure in JEWEL"*, J. G. Milhano and K. Zapp, Eur. Phys. J. C82 (2022) no.11, 1010
- *"Multiparticle production in proton-nucleus collisions beyond eikonal accuracy"*, P. Agostini, T. Altinoluk, N. Armesto, F. Dominguez and J. G. Milhano, Eur. Phys. J. C82 (2022) no.11, 1001
- *"Flavour-Changing Neutral Scalar Interactions of the Top Quark"*, Nuno Castro, Kirill Skovpen, Universe 2022, 8, 609
- *"Heavy quarks and jets as probes of the QGP"*, Liliana Apolinário, Michael Winn, Yen-Jie Lee, Prog.Part.Nucl.Phys. 127 (2022) 103990

4 International Conference Proceedings

- *"A Time Reclustering Algorithm for Jet Quenching Studies"*, Liliana Apolinário, André Cordeiro, Korinna Zapp, PoS PANIC2021 (2022) 248
- *"Deciphering the role of multiple scatterings and time delays in the in-medium emission process"*, Carlota Andres, Liliana Apolinario, Fabio Dominguez, Marcos Gonzalez Martinez, Carlos A. Salgado, PoS PANIC2021 (2022) 252
- *" Status of NNLO QCD corrections for process with one or more jets in the final state at the LHC"*, Joao Nuno Pires, PoS PANIC2021 (2022) 394
- *"Jet rapidity distributions and jet-jet correlation functions"*, N. Bethencourt de León, G. Chachamis and A. Sabio Vera, Phys.Scripta 97 (2022) 7, 074007

1 LIP Students Note(s)

- *"Building a QCD parton shower"*, Diogo Costa, Ana Carolina Ribeiro, LIP-STUDENTS-22-05

Presentations

3 Oral presentations in international conferences

- Liliana Apolinário: *"New winds in heavy-ion physics"*, 2022-05-02, DIS 2022, Santiago de Compostela, Spain
- Abideh Jafari, Eleni Vryonidou, Nuno Castro: *"Report from the LHC EFT WG"*, 2022-06-15, LHC TOP WG general workshop, CERN / online
- Liliana Apolinário: *"Overview of jet quenching theory"*, 2022-08-02, XVth Quark Confinement and the Hadron Spectrum, Stavanger, Norway

1 Poster presentation(s) in international conference(s)

- Liliana Apolinario, Pablo Rodriguez, Korinna Zapp: *"Deciphering Jet Quenching Effects with Novel Reclustering Tool"*, 2022-04-06, Quark Matter 2022, Krakow, Poland (remote)

3 Oral presentations in national or international meetings

- Liliana Apolinário, André Cordeiro, Pablo Guerrero-Rodriguez and Korinna Zapp: *"Time reclustering for jet quenching"*, 2022-06-16, ECT* Jet Quenching in the Quark-Gluon Plasma, Trento, Italy
- Pablo Rodriguez: *"Evolution of initial stage fluctuations in the Glasma"*, 2022-09-25, Diffraction and Low-x 2022, Corigliano Calabro, Italy
- Liliana Apolinario, Pablo Rodriguez, Korinna Zapp: *"Jet Substructure as a Tool for Quark Gluon Plasma Tomography"*, 2022-12-20, VI FTAE Christmas workshop, Granada, Spain

4 Seminars

- Pablo Rodriguez: *"Initial Stage Fluctuations in Heavy Ion Collisions"*, 2022-02-10, Seminar at LIP, LIP, Lisbon, Portugal
- Liliana Apolinário: *"What do we know about the Quark-Gluon Plasma?"*, 2022-05-18, Coimbra, Portugal
- Guilherme Milhano: *"What we have learnt from jet quenching at the LHC"*, 2022-06-23, Lip Seminar, LIP, Lisboa, Portugal;
- Guilherme Milhano: *"What is a quenched jet ?"*, 2022-09-08, Physics Coffee, Lund University, Sweden

Theses

9 PhD

- Guilherme Guedes: *"Collider and astrophysical constraints to little Higgs models"*, 2018-11-21 / 2022-09-16, (finished), UMinho, Supervisor(s): Nuno Castro, José Santiago Perez
- Esteban Chalbaud: *"Probing CP couplings in ttX production at the Run3 of the LHC"*, 2021-11-29 / 2025-12-31, (ongoing), UC, Supervisor(s): António Onofre
- Susana Santos: *"Study of the ttH production and Higgs couplings to Top quarks in the ATLAS experiment"*, 2010-10-30, (ongoing), UC, Supervisor(s): António Onofre

- Mariana Araújo: *"Quarkonium production studies at LHC energies: towards the understanding of bound-state formation by the strong force"*, 2018-02-12 , (ongoing), IST, Supervisor(s): Pietro Faccioli, Carlos Lourenço
- João Martins da Silva: *"The substructure of in-medium jets"*, 2021-05-01 , (ongoing), IST, Supervisor(s): Guilherme Milhano, Liliana Apolinário
- João Martins da Silva: *"The substructure of in-medium jets"*, 2021-05-01 , (ongoing), IST, Supervisor(s): Guilherme Milhano, Liliana Apolinário
- João Arruda Gonçalves: *"Disentangling and Quantifying Jet-Quenching With Generative Deep Learning"*, 2021-09-01 , (ongoing), IST, Supervisor(s): Guilherme Milhano
- André Cordeiro: *"Jetography in Heavy Ion Collisions"*, 2021-12-07 , (ongoing), IST, Supervisor(s): Liliana Apolinário, Guilherme Milhano
- Fernando Souza: *"AutoBSM: Validating Beyond the Standard Model Physics with Machine Learning"*, 2022-05-01 , (ongoing), UMinho, Supervisor(s): Miguel Romão, Nuno Castro
- Dario Vaccaro: *"Formal and phenomenological studies in the high energy limit of QCD "*, 2022-09-01 , (ongoing), IST, Supervisor(s): Grigorios Chachamis, Guilherme Milhano
- João Lopes: *"Looking for (de)coherence effects in the Quark-Gluon Plasma"*, 2021-10-01 / 2022-12-31, (finished), IST, Supervisor(s): Liliana Apolinário
- João Humberto Gomes: *"Deep Learning in QCD Jets"*, 2021-09-29 / 2023-02-27, (finished), UC, Supervisor(s): Ricardo Gonçalo, Liliana Apolinário
- Marco Leitão: *"Disentangling QGP response using energy flow correlators"*, 2022-10-17 / 2023-10-16, (ongoing), IST, Supervisor(s): Guilherme Milhano
- Guilherme Crispim: *"Pre-equilibrium of the Quark-Gluon Plasma"*, 2022-11-07 / 2023-12-31, (ongoing), IST, Supervisor(s): Liliana Apolinário
- Guilherme Calé: *"Jet jet correlations in QCD "*, 2020-09-09 , (ongoing), FCUL, Supervisor(s): João Nuno Pires, Grigorios Chachamis
- Tomás Cabrito: *"The soft-hard antenna spectrum in presence of a QGP"*, 2020-11-01 , (ongoing), IST, Supervisor(s): Guilherme Milhano, Liliana Apolinário
- Lénea Luís: *"Deciphering jet quenching effects through a quantile ratio"*, 2022-03-23 , (ongoing), IST, Liliana Apolinário, Supervisor(s): Guilherme Milhano

11 Master

- Nuno Madureira: *"Jet substructure tools to identify hadronization timescales"*, 2021-10-01 / 2022-11-16, (finished), IST, Supervisor(s): Liliana Apolinário,
- Manuel Mariano: *"Sensitivity of jet sub-structure observables to jet quenching in collisions of light nuclei "*, 2022-02-01 / 2022-11-23, (finished), IST, Supervisor(s): Guilherme Milhano, Liliana Apolinário
- Francisco Barreiro: *"Geometrical aspects of jet quenching in small systems"*, 2022-02-01 / 2022-11-23, (finished), IST, Supervisor(s): Guilherme Milhano, Liliana Apolinário
- Beatriz Artur: *"Impact of Quark-Gluon Plasma in Extensive Air Showers"*, 2021-10-01 / 2022-12-02, (finished), IST, Supervisor(s): Ruben Conceição, Liliana Apolinário

RESEARCH / LHC EXPERIMENTS AND PHENOMENOLOGY

FCC

Participation in the FCC feasibility study

Principal Investigator:
Ricardo Gonçalo (19)

7 ***Researcher(s):***
Grigorios Chachamis (15), Guilherme Milhano (11), Inês Ochoa (11), João Nuno Pires (26), Michele Gallinaro (2), Patricia Conde (11), Rute Pedro (15)

1 ***PhD Student(s):***
Beatriz Pinheiro Pereira (11)

2 ***Master Student(s):***
Francisco Casalinho (50), Joana Reis (25)

1 ***Undergraduated Student(s) and Trainee(s):***
Diogo Pires Nunes

Total FTE:
2 (PhD 1.1)

Nat.& Internat. meetings: **1** Oral presentation(s)
Notes: **1** LIP Students note

Executive summary

The FCC group at LIP is currently focused on contributing to the ongoing feasibility study for the Future Circular Collider (FCC). More generally, it aggregates research interests on future collider-based HEP projects and facilities, to boost the long-term participation of LIP in the future of particle physics.

The group grew from a core of members from the ATLAS, CMS and Phenomenology groups at LIP, who were involved in the production of the FCC Conceptual Design Review, one of the inputs to the most recent update of the European Strategy for Particle Physics.

In 2022, activity grew along a few lines of development: R&D on new radiation-hard scintillators and detector simulation, an analysis feasibility study, and theoretical calculations of Standard Model parameters relevant for the FCC-ee programme. A small project funded by FCT has allowed us to initiate this research activity, which is currently consolidating.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Michele Gallinaro		115.000 €	2022-01-01 to 2025-12-31	aAmuse - Project 101006726 / aAmuse - advanced Muon Campus in US and Europe contribution
João Nuno Pires (Ricardo Gonçalo)	FCT	15.000 €	2022-04-01 to 2024-03-31	CERN/FIS-PAR/0035/2021 / PPatFCC_Participação Portuguesa no Futuro Colisionador Circular (FCC)

FCC

Overview

Following the 2020 update of the European Particle Physics Strategy (EPPS), a global collaboration was established, dedicated to producing a feasibility study for a Future Circular Collider (FCC) facility located in Geneva. If approved, this facility will represent the future high-energy frontier in accelerator physics, and will succeed the High Luminosity LHC from around 2040 onwards. It will include an e+e- collider (FCC-ee) devoted to a broad physics programme with highlights in Higgs, top and electroweak precision measurements. FCC-ee will later be replaced by a hadron machine (FCC-hh), which will share most of the infrastructure of the previous collider and repeat the virtuous cycle represented by LEP and the LHC. The FCC-ee will allow improving our understanding of the SM by precisely measuring key parameters of the model, thus enhancing the sensitivity to new physics. This will allow a future generation of physicists to explore the limits of the Standard Model and possibly reach beyond, to a more fundamental theory. FCC-hh will later enhance the current energy frontier by an order of magnitude, providing the students of our students with the broadest experimental possibilities that we can envisage.

This group was created at LIP to take part in the FCC endeavour, concentrating in the Physics, Experiments and Detectors area within the international FCC Collaboration. The first goal of this collaboration is to complete a full feasibility study of the FCC facility, its planning and physics prospects, by 2025, in time for the next ESSP update. The FCC group harbours both physics studies and technology developments relevant to the FCC.

The FCC-ee experiments will require a totally new level of detector precision, with instrumental uncertainties well understood to the per-mille level. Experiments for the FCC-hh, on the other hand, will demand extremely radiation-hard but very highly granular detectors. In both cases, opportunities are created for new ideas in instrumentation R&D, which LIP should profit from. These opportunities are mirrored by the ECFA detector development roadmap, which will foster and support technological developments for future colliders. The detailed definition of the FCC-ee/-hh physics case, and the careful assessment of the reach of these colliders, also creates ample avenues for theoretical and experimental physics research.

Assessment of the past year: objectives vs. achievements

Activity over the past year developed in the following areas: detector R&D, Higgs studies at the FCC-ee, and QCD observable calculations.

On the detector area, we have started to develop novel radiation-hard scintillators based on PET (Polyethylene Terephthalate) and PEN (Polyethylene Naphthalate) plastics. This work was done at the LOMaC laboratory at LIP and in collaboration with the Institute for Polymers and Composites (IPC), in Minho. We have also become involved in FCC-ee calorimeter simulations, with a PhD student spending part of her time working on this, in collaboration with a group at CERN. The scintillator work has started, with first PET and PEN scintillator samples produced and awaiting a detailed study.

Sensitivity studies in the Higgs sector at the FCC-ee were started, with a MSc student developing an analysis of di-Higgs production to search new ideas in order to enhance the limited physics reach of the collider in this area. Results have not been encouraging so far, but have provided insight into the possibilities offered by the planned collider. Two students participated in the LIP Summer Internships on a FCC project in the area of Higgs physics.

On the QCD theory side, a MSc thesis project has started with the aim of performing comprehensive QCD studies for the FCC-ee physics program. In particular, with the foreseen FCC-ee run at the Z-pole, the determination of the strong coupling constant from the ratio of the Z hadronic width to the Z leptonic width, will greatly benefit from the available statistics (10^5 order improvement with respect to LEP). To this end, the student is implementing b-quark mass effects in QCD three-jet production observables produced by the hadronic decays of the Z-boson when the FCC-ee collider is running at the Z-pole in a Monte Carlo event generator. The aim is to perform a next-to-leading order calculation of this process and study the quantitative effects of including the bottom-quark mass in the calculation. Given the projected experimental precision of the FCC-ee machine, it is expected that these effects are necessary for a complete phenomenological description of this process at the FCC-ee. This project is particularly relevant to the ongoing feasibility study of the physics potential of the future circular collider.

Lines of work and objectives for next year

During the coming year we plan to reach significant milestones in the ongoing projects.

On the detector R&D front, we plan to produce samples of larger PET/PEN scintillators and try different material mixtures at IPC/UMinho, and study their performance at LOMaC, aiming for a publication. We also plan to continue to participate in the simulation of a future FCC calorimeter, contributing to the ECFA Detector R&D Roadmap.

On the Higgs and QCD fronts we plan to reach conclusions on the ongoing studies, leading to two MSc theses. These results may be relevant to the physics case of the FCC, but the conclusions are yet uncertain.

At this point, it is unlikely that we will have much contribuition to the FCC mid-term report in Q3 of 2023, due to the tight schedule. But in the longer term, our goal is to give valuable contributions to the FCC feasibility study to be released in 2024/25.

Medium-term (3-5 years) prospects

In the medium term, our main goal is to diversify the group's activity and make relevant contributions to the FCC feasibility study by 2025. This is a small group of researchers already committed to other urgent tasks. But we aim to grow in numbers and breadth of subject in the coming years. This area has already attracted the activity of 1 PhD (part of her time) and 2 MSc students and has the potential to attract more.

On the experimental side, the group aims to expand the R&D activities on calorimetry, building up on expertise from the LHC. The possibility of producing plastic scintillators in Portugal for future particle physics experiments and applications, is attractive and will also strengthen these activities.

On the physics case and theory side, the energy reach and intended precision of FCC physics bring the promise of experimentally probing Beyond the Standard Model physics but also demand a large jump in the precision of existing calculations. Both aspects will focus theoretical interest in this area at LIP and outside, which we plan to explore.

We believe the FCC facility will be an essential part of the future of both CERN and particle physics in Europe, and want to be a part of that.

SWOT Analysis

The SWOT analysis is not much diferent from last year:

Strengths

The breadth of experience in collider physics concentrated in the group, as well as the geographic and institutional diversity of our members, will help to contribute to a wide set of subjects and to attract more interest from students and colleagues.

Weaknesses

The FCC is not the main or the only interest of any of the current group members, which subjects our work programme to the needs of other topical theory studies or on-going LHC experimental upgrades.

Opportunities

The current FCC Feasibility Study and the ECFA Detector Roadmap present opportunities to initiate a work programme that will lead to a long-term, unique facility in particle physics. LIP should take part in this endeavour.

This project provides an interesting opportunity for undergraduate and master students to participate in the initial studies of a facility that may be part of their future. This is in fact already happening in our group. These studies are also of wider applicability than the FCC project.

Threats

Only shortness of dedicated research time, which may prevent a meaningful contribution.

Publications

1 LIP Students Note(s)

- *"Probing the vaccum with di-Higgs production"*, Diogo Pires Nunes, Francisco Casalinho, LIP-STUDENTS-22-09

Presentations

1 National and International meeting(s)

- *"FCC@LIP*, Ricardo Gonçalo, Jornadas LIP 2022, Coimbra

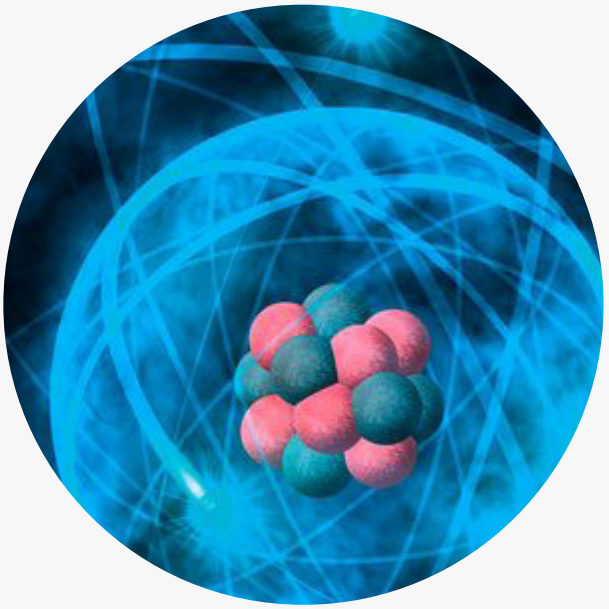
Theses

1 PhD

- Beatriz Pinheiro Pereira: *"Radiation Damage of Optical Components in Scintillator Detectors: from the ATLAS/LHC Tile Calorimeter to Future Experiments"*, 2021-02-01 , (ongoing), IST, Supervisor(s): Rute Pedro, Patricia Conde

2 Master

- Francisco Casalinho: *"Probing the vaccum with di-Higgs production"*, 2022-09-27 , (ongoing), UC, Supervisor(s): Ricardo Gonçalo, Filipe Veloso
- Joana Reis: *"Implementation of quark mass effects in QCD three-jet production observables produced by hadronic decays of the Z-boson at FCC-ee collider"*, 2021-09-15 , (ongoing), FCUL, Supervisor(s): João Nuno Pires,



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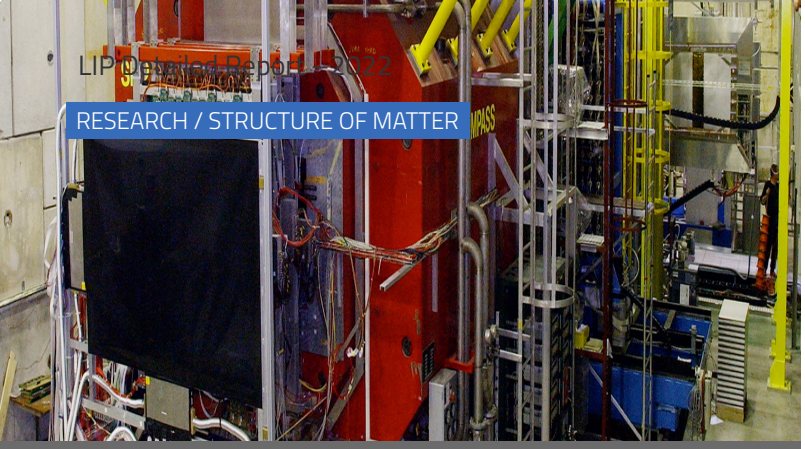


P&QCD

Participation in the COMPASS and AMBER experiments at CERN

Principal Investigator:
Catarina Quintans (100)

2 ***Researcher(s):***
Marcin Stolarski (70), Pietro Faccioli (25)

1 ***Technician(s):***
Christophe Pires (100)

1 ***Master Student(s):***
Rita Silva (100)

3 ***Undergraduated Student(s) and Trainee(s):***
Catarina Corte-Real, Guilherme Almeida, Guilherme Amaral

3 ***External collaborator(s):***
Frantisek Voldrich, Márcia Quaresma, Sofia Nunes

Total FTE:
4 (PhD 2)

Articles in international journals:	**1** Direct contribution
Notes:	**1** LIP Students note
International conferences:	**3** Oral presentations **1** Proceeding
Nat.& Internat. meetings:	**1** Oral presentation **1** Poster
Collaboration meetings:	**4** Oral presentations
Advanced Training Events:	**1** Student presentation
Completed theses:	**1** MSc **1** BSc

Executive summary

The AMBER experiment at CERN officially started its data-taking phase in 2022, with two short beam tests. The goals were to tune the proton beam and collect small data samples at varying beam momenta (60, 100 and 250 GeV/c), while testing the new Unified Tracking Stations (UTS) and the new Triggerless Data Acquisition mode. The preliminary analysis allowed to validate the procedures and confirmed the beam characteristics, essential steps for the antiproton production cross-section measurement that will take place in 2023. The UTS includes the new ALPIDE silicon pixel sensors (ALICE development) and the new Scintillating Fiber Hodoscopes (FSH). The UTS will be used in the proton radius measurement of AMBER, whose pilot Run will happen in the second half of 2023.

The COMPASS experiment at CERN completed its data-taking phase in 2022 , with the precision measurement of the d-quark tensor charge from Deep Inelastic Scattering on transversely polarized LiD target. COMPASS now enters a phase of data analysis. An agreement between COMPASS and AMBER collaborations settled the transfer of the hardware equipment and responsibilities.

The AMBER Memorandum-of-Understanding was prepared and will be signed by the participant representatives in the course of 2023.

In 2022 the group ensured a permanent presence and expert support to the Detector Control System (DCS). Christophe Pires was elected COMPASS Run co-coordinator 2022. The group fulfilled its responsibilities in the data taking, with four members taking shifts. Christophe Pires is a member of the AMBER Technical Board, and he was also member of the COMPASS Technical Board in 2022. Marcin Stolarski is a member of the AMBER Publications Committee (since September 2022). Catarina Quintans completed her four years duty as member of the COMPASS Publications Committee in October 2022. Catarina Quintans is also coordinator of the COMPASS Drell-Yan physics group. In 2022 this physics group was directly responsible for four major releases of results and one submitted paper.

The main responsibilities of the group in AMBER are on the Drell-Yan topic, namely on physics simulations that include the new detectors and setup modifications, and in developing new analyses approaches for beam particle identification using CEDARs (Cherenkov Differential Counter with Achromatic Ring Focus). In June 2022, an MSc student from Czechia, Frantisek Voldrich, co-supervised by Marcin Stolarski, completed his thesis on this latter topic. In November 2022, MSC student Rita Silva under the co-supervision of Catarina Quintans completed her thesis in the former topic.

The modification of the COMPASS DCS to the AMBER conditions is also being done by the group. A proposal for the AMBER second-phase (after LS3) is in preparation. There is close collaboration between the LIP group and the Aveiro group in COMPASS and AMBER, namely in the tasks related to AMBER simulations, and supervising students working on these tasks.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Catarina Quintans (Carlos Azevedo, UA)	FCT	165.000 €	2021-10-01 to 2023-09-30	CERN/FIS-PAR/0016/2021 / COMPASS/AMBER_Colaboração nas Experiências COMPASS e AMBER do CERN

P&QCD

Overview

The LIP group "Partons and QCD" participates in COMPASS and AMBER experiments at CERN. The group has technical expertise in Detector Control Systems, under the responsibility of C. Pires. He is also a member of the Technical Boards of COMPASS and AMBER.

The main activity of the group is data analysis. C. Quintans is the coordinator of the COMPASS Drell-Yan physics group. P. Faccioli, expert in phenomenological studies of Quarkonium, is giving support to the J/psi studies in COMPASS. C. Quintans directly participates in the analyses for the Drell-Yan cross-section measurement and for the J/psi production cross-sections ratio between tungsten and aluminium targets.

M. Stolarski plays a leading role in the COMPASS analyses related to hadron multiplicities. In 2022 he completed the evaluation of radiative corrections on the multiplicities. In parallel, he works on the development of a deep neural networks method for the AMBER beam particle identification using information from CEDARs. M. Stolarski is a member of the AMBER Publications Committee.

The group is strongly involved in the AMBER Drell-Yan program, by performing physics simulations, and in the concept discussions related to the Drell-Yan and Charmonium studies. The AMBER measurements will extend the physics goals of COMPASS. With the completion of the COMPASS analyses in which the group is involved, the activities will gradually shift to AMBER. The AMBER 2023 Run will include the antiproton production cross-section measurement (APX) from proton beam on a helium target, with variable beam momentum. The APX measurements will last two months. It will be followed by a pilot Run for the proton radius measurement from muon-proton elastic scattering, lasting three months. The LIP group will focus mostly in the first part, namely the aspects related to the hadron beam particle identification and beam tracking, as these are crucial aspects to prepare also the Drell-Yan measurements that should take place from 2025.

The group includes presently two students: Rita Silva, who completed her MSc thesis in 2022 and plans to start a PhD in the AMBER Drell-Yan program; and Guilherme Almeida, who is performing Drell-Yan physics simulations in the AMBER conditions.

Assessment of the past year: objectives vs. achievements

Members of the group contributed to several ongoing Drell-Yan and Charmonium analyses, namely as coordinators, supervisors and analysers. C. Quintans is the COMPASS Drell-Yan group coordinator. In 2022 large and improved Monte Carlo (MC) samples were produced for all the physics processes relevant to the dimuon spectra under study. MC generation and reconstruction was also one of the tasks of C. Quintans. The MC samples were crucial for the release of results on the J/psi cross-section ratio W/Al as a function of dimuon transverse momentum and Feynman-x variables, in August 2022. These studies had direct contributions from C. Quintans and P. Faccioli. The results were presented at two workshops during 2022.

The Drell-Yan cross-section measurement analysis was also expected to have results released in 2022. This goal was not yet achieved. A discrepancy between the cross-section measurements from two different (but partially overlapping) dimuon triggers motivated further systematic studies, that are still ongoing.

The data collected in 2016 and 2017 by COMPASS using muon beams of both charges and a liquid hydrogen target is being studied by M. Stolarski, who focuses on the hadron multiplicities and fragmentation functions (FFs). One of the missing ingredients in the analysis was the estimation of radiative corrections, a major effort that was concluded in 2022. These radiative corrections can be as large as 70% in the region of very-high y, excluded from the analysis. They are seen to increase with z (fraction of energy carried by the hadron) and decrease with pT (hadron transverse momentum). If neglected, they can also lead to artificially large negative Cahn effect observed in azimuthal transverse spin asymmetries.

Physics simulations of the Drell-Yan measurements proposed by AMBER have progressed during 2022, with important contribution from the students in the LIP group, and in close collaboration with the Aveiro group. In November 2022 Rita Silva successfully completed her MSc thesis on the study of the impact of a vertex detector in the planned Drell-Yan setup.

A method for beam particle identification using neural networks for pattern recognition in CEDARs was developed by F. Voldrich, MSc from Czechia co-supervised by M. Stolarski. The student spent periods with the Lisbon group in two occasions (November 2021 and April 2022). The thesis was successfully completed in June 2022, and the results were presented by F. Voldrich at the ICHEP 2022 conference. The group plans to proceed further studies using this approach, as the beam particle identification is crucial for the feasibility of the AMBER measurements.

C. Quintans contributed to the studies concerning hadron beams for AMBER, both conventional and radio-frequency separated, together with the CERN Beam Department and others. These studies lead to the publication of a paper in NIMA. In view of the preparation of the scientific proposal for AMBER phase-II, the series of workshops “Perceiving the Emergence of Hadron Mass”, started in 2019, had one remote edition in May 2022, co-organized by C. Quintans.

The COMPASS 2022 Run concluded the experiment's data taking program. The DCS, a responsibility of the LIP group, was maintained by Christophe Pires and worked in a stable and reliable way during the whole Run. C. Pires was also Run co-coordinator. There was a smooth transition from the DCS of COMPASS to the DCS of AMBER, that worked well during the AMBER beam tests, in spite of the fact that only part of the planned detectors were ready in time or only prototypes could be tested.

Lines of work and objectives for next year

The LIP group plans to proceed with the same lines of work explored so far. The COMPASS analyses in which the group is presently directly involved should be continued: the Drell-Yan cross-section measurement from 2018 data; the J/psi production cross-section ratio W/Al; and the hadron multiplicities produced in semi-inclusive DIS (SIDIS), from 2016 data. While the J/psi analysis had a preliminary release of results in August 2022, the acceptance as well as the background contribution evaluations were significantly improved meanwhile. The analysis should thus be repeated taking advantage of these progresses. Both the Drell-Yan cross section and the hadron multiplicities from SIDIS analyses should release results in 2023. One paper on the topic of Drell-Yan azimuthal transverse spin asymmetries is presently in preparation.

The AMBER Drell-Yan measurements in phase-I are planned to have a pilot Run in 2025 and in principle the physics data taking should happen in 2026 or 2028 (depending on the period for the CERN Long Shutdown 3). One of the group's main activity is expected to be the optimisation of the setup for that measurement. The student Guilherme Almeida will do simulations for a modified setup where some of the COMPASS detectors will be replaced by new detectors presently being discussed. The study done by Rita Silva on the impact of a vertex detector in the dimuon events reconstruction shall proceed with a more precise implementation in the simulation chain of the FVTX detector (from the PHENIX experiment at RHIC), which will probably be the vertex detector chosen for the Drell-Yan setup. Rita Silva will start her PhD work by studying the beam particle identification using CEDARs and the beam reconstruction from an upgraded AMBER beam telescope, both in the real data from the 2023 APX Run and using dedicated simulations.

The group will also continue contributing to the preparation of the AMBER proposal for phase-II measurements, planned to be made public before the end of 2023.

Medium-term (3-5 years) prospects

The medium-term prospects for the group are to conclude the COMPASS data analyses that are presently ongoing, and write the corresponding papers. This concerns specifically the pion-induced Drell-Yan cross-section measurement; the Drell-Yan transverse spin asymmetries extraction; the J/psi production cross-section ratio from tungsten and aluminium targets; and the hadron multiplicities on hydrogen target measurement.

The first measurement of AMBER will be the antiproton production cross section from proton beam at different momenta on a helium target. The measurement will provide important input for Dark Matter Searches and the interpretation of antiparticle fluxes from cosmic measurements. The data taking will be done during two months in 2023.

Another AMBER measurement already approved for phase-I is the proton radius measurement from high-energy muon-proton elastic scattering. The pilot run will be in the second half of 2023, using the IKAR TPC (smaller than the one in the AMBER proposal). The TPC filled with high pressure hydrogen acting also as target serves as recoil detection medium, while the Unified Tracking Stations comprising silicon pixel detectors (ALPIDE sensors) and Scintillating Fiber Hodoscopes, will provide the tracking of the incoming and scattered muon emitted at very small angle. In principle the main proton radius measurement Run will start in 2024, and last for one and a half years.

The AMBER Drell-Yan measurements, a main physics interest for the LIP group, may start in 2025, with a pilot run where the full setup and the newly implemented level-one dimuon trigger will be tested. The setup shall include a vertex detector, additional trackers in the beam telescope, an upgraded beam particle identification system (CEDARs based), and new scintillating slabs-based hodoscopes for muon detection. These topics are being studied by the group. The main data-taking may happen in 2026 or 2028, depending on the programmed CERN Long Shutdown (LS3).

In parallel, the group continues its contribution to the AMBER Phase-II studies and proposal writing, with the prospect of the approval of the first accurate experimental study of kaon structure.

SWOT Analysis

Strengths

Members of the LIP group are responsible for several analyses and coordinate the Drell-Yan group in COMPASS. The LIP group is also responsible for the DCS, a field in which it has highly recognized expertise, and cooperates with the CERN Controls and Automation groups in the development of new software implementations.

Weaknesses

The LIP group has lost several members in recent years, mostly due to the precarious employment situation. The small dimension of the group is presently a limiting factor in the activities we develop. Further students supervision, beyond the two already integrated in the group and those hosted during the LIP Summer Internships and ERASMUS+ internships, cannot be foreseen.

Opportunities

The start of AMBER is a big opportunity for the LIP group to play a major role in this new CERN experiment. The group has the physics background and the experience needed. AMBER is attractive for new students and two students are presently contributing, one of them starting PhD.

Threats

The precarious employment situation of some members of the group continues to be a serious threat. The present COMPASS/AMBER project is financed from FCT until September 2023, a new project will be submitted for the following 2 years). The shared costs of setting up a new experiment go much beyond what this project budget can cover. The signing of the AMBER MoU must still be negotiated, and alternative financial solutions must be explored.

Publications

1 Article(s) in international journals (with direct contribution from team)

- *"Design of beam optics for RF-separated kaon and antiproton beams in the M2 beam line of the CERN North Area"*, A. Gerbershagen et al., NIM A 1048 (2023) 168004

1 Article(s) in international journals (with internal review by the team)

- *"Exotic meson π1(1600) with JPC = 1^{− +} and its decay into ρ(770)π"*, G.D. Alexeev et al (COMPASS Coll.), Phys.Rev. D 105, 012005 (2022)

1 International Conference Proceedings

- *"The New AMBER Experiment at the CERN SPS"*, C. Quintans on behalf of the AMBER Coll., Few-Body Syst 63, 72 (2022)

1 LIP Students Note(s)

- *"Identification of kaons using Neural Networks in COMPASS and AMBER experiments at CERN"*, Guilherme Amaral, LIP-STUDENTS-22-28

Presentations

3 Oral presentations in international conferences

- C. Quintans on behalf of the AMBER Coll.: *"The Hadron structure as seen by the AMBER experiment"*, 2022-03-10, CPHI 2022: Correlations in Partonic and Hadronic Interactions 2022, Duke University, North Carolina, USA & Remote
- C. Quintans on behalf of COMPASS and AMBER: *"Cold nuclear matter effects from charmonium measurements"*, 2022-09-12, Revealing emergent mass through studies of hadron spectra and structure workshop, ECT* Trento Italy and remote
- Catarina Quintans (on behalf of the AMBER Coll.): *"Investigating the structure of matter with the AMBER experiment"*, 2022-11-07, Baryons 2022 – International Conference on the Structure of Baryons, Sevilla, Spain

1 Oral presentation(s) in national or international meeting(s)

- Catarina Quintans: *"Partons and QCD"*, 2022-07-09, Jornadas LIP 2022, Coimbra

1 Poster presentation(s) in national or international meeting(s)

- Rita Silva and Guilherme Almeida: *"The AMBER experiment at CERN"*, 2022-07-08, Jornadas LIP 2022, Coimbra

1 Student presentation(s) in advanced training event(s)

- Guilherme Amaral: *"Identification of kaons using Neural Networks in COMPASS and AMBER experiments at CERN"*, 2022-09-09, LIP Internship program 2022 final workshop, LIP, Lisboa

Theses

1 Master

- Rita Silva: *"Optimisation studies for the pion-induced Drell-Yan measurement at the AMBER experiment"*, 2021-11-14 / 2022-11-23, (finished), IST, Supervisor(s): Catarina Quintans.

1 Licentiate

- Frantisek Voldrich: *"Identication of Beam Particles Using CEDAR Detectors and Machine Learning in the COMPASS Experiment at CERN"* (finished on 2022-05-31) Supervisor(s): Marcin Stolarski.

HADES (*)

Collaboration in the HADES experiment at GSI

Principal Investigator:
Alberto Blanco

1 ***Researcher(s):***
Paulo Fonte

2 ***Technician(s):***
João Saraiva , Luís Lopes

Articles in international journals:	**1** Direct contribution
	1 Poster
International conferences:	**1** Oral presentation
	1 Poster
Collaboration meetings:	**1** Oral presentation
Organized Events:	**1** Collaboration Meeting

* No specific HR have been allocated, due to the lack of funded projects. Nevertheless, the tasks to be developed in HADES are covered within the RPC R&D group planning.

Executive summary

The LIP-HADES group was originally created for the design and construction of a Time of Flight (TOF) detector based on Resistive Plate Chambers (RPCs), the RPC-TOF-Wall (RPC-TOF-W), for the HADES spectrometer, operated at GSI, Darmstad, Germany. After this initial period, a team from the LIP COMPAS group joined the HADES group and focused on data analysis. This synergy had important results such as the publication of a paper in Nature Physics ("Probing dense baryon-rich matter with virtual photons". Nat. Phys. 15, 1040–1045 (2019)) with the direct contribution of the group. After this, the group lost the people involved in data analysis (due to other commitments) and was reduced again to hardware activities. Besides the operation of the RPC-TOF-W, hardware activities were recently complemented with the construction of a new RPC TOF detector for the HADES forward region, the RPC-TOF-FD, and with a strong collaboration with the Multi Drift Chamber (MDC) group with the aim of preparing the HADES tracking system for FAIR.

The proposed work plan for 2022 was almost fully achieved. The highlight of the year was the proton-on-proton (@4.5 GeV) production beam time, which put into operation, for the first time, an RPC detector that increases its count rate capability by increasing its operational temperature (taking advantage of the decrease in glass resistivity as the temperature increases). The outbreak of the war in Ukraine in February 2022 severely affected the GSI/FAIR phase-0 physics program. This crisis (mainly the increase of electricity prices in Germany) made access to accelerator time more difficult. As a consequence HADES has no beam time allocated during 2023. At the moment, the next run, dedicated to heavy ions, is scheduled for early 2024. This situation, in conjunction with Russia's exit from FAIR (where it was a key element in the construction) made the FAIR schedule quite uncertain in the moment.

The Memorandum of Understanding (MoU) signed between HADES and the Portuguese funding agency FCT expired at the end of 2022. Due to bureaucratic constraints at FCT the new MoU cannot be signed. We expect the situation to be solved and the MoU to be signed during 2023.

In recent years the activities of the LIP HADES group have been financially supported by a modest amount (12 k€/year) in the framework of this MoU. In addition, the HADES collaboration has strongly supported our work, paying for travel, accommodation and material for the RPC detectors (the estimated contribution is 12 k€ in 2022). As this support will be maintained in 2023, the current situation is not an obstacle to the development of the work As for human resources, while there are practically no FTEs allocated to HADES, the group is very closely related to the LIP RPC R&D group, Mechanical Workshop and Detectors Lab, which take into account the HADES needs in their planning.

Finally, it is worth mentioning that the HADES collaboration meeting was held in Coimbra in September 2022, with more than 50 members present and 30 remotely connected.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Alberto Blanco	FCT	12.000 €	Yearly budget	HADES-FCT-MoU / MoU between HADES and FCT

HADES

Overview

Presently, the LIP HADES group is involved only in hardware-activities, with the followng tasks:

- RPC-TOF-W and RPC-TOF-FD operation. Operation of the RPC-TOF-W and RPC-TOF-FD within the data taking periods and collaboration in general duties related to data taking periods as HADES DAQ operator and shift leader. Responsibility: A. Blanco, P. Fonte, L. Lopes and J. Saraiva.
- Preparing the HADES Tracking System for High-Rate Experiments at SIS100. The future physics program of HADES at FAIR demands high detection standards and stability of the tracking system due to the expected increase of the beam energies and intensities. The LIP-HADES group collaborates in this task with the MDC group. Responsibility: L. Lopes.

Assessment of the past year: objectives vs. achievements

The objectives of the group, as stated in the last report, were:

- Production beam run (four weeks of data taking in February) with p+p at 4.5 GeV. This is the first production beam time with the new RPC-TOF-W DAQ system and especially for the RPC-TOF-FD, The performance of the system will fially be fully evaluated. This will demonstrate the feasibility of increasing the count rate capability of an RPC detector by increasing its operating temperature.
- Calibration and low level data analysis of the data gathered in February.
- Finalize the construction of the spare module for RPC-TOD-FD.
- Optimization of the gas system of the tracking with the aim of increasing the longevity of the system.

The production run with p+p at 4.5 GeV scheduled for February was carried out as planned and was considered, from the point of view of the experiment and specifically of the RPC detectors, a success.

The new DAQ installed in the RPC-TOF-W (the previous DAQ, based in outdated boards, limited the trigger rate of the spectrometer) worked perfectly and the performance of the system remained unchanged. The detector itself worked perfectly during the whole period of data taking.

Concerning the RPC-TOF-FD everything worked as expected. The detector was operated at a maximum particle flux (near the beam axis) of 600 Hz/cm². To accommodate this particle flux the operating temperature of the detector was increased to 31.5ºC, exploiting the decrease in resistivity as the temperature increase.

The behavior of the detector under these conditions was previously tested and results were presented this year at the 15th Pisa Meeting on Advanced Detectors and published. Preliminary results from the full system were presented at the 16th Workshop on RPC at CERN, and submitted for publication. They show an intrinsic time resolution of 80 ps, below the experimental requirement of 100 ps.

The group collaborated closely in the calibration and low-level analysis of the data acquired in the February run with the RPC-TOF-FD, together with the Polish group in charge of implementing the code for this purpose.

Due to the delay in the physics program, caused by the Russian invasion of Ukraine, and not being immediately necessary, the construction of the spare module for the RPC-TOF-FD was not completed. For the same reason, actions related to the optimization of the gas system for the tracking system were also postponed.

Although not initially scheduled, one of the sectors of the RPC-TOF-W was dismounted at the end of the year to allow the installation of the last sector of the ECAL detector (at the rear of the RPC detector).

Lines of work and objectives for next year

- Although the operation of the RPC-TOF-FD was successful, there are small details that need to be studied. In particular, we are currently having to work at high gas flow and need to understand why. This happens also without particle irradiation and could be due to poor gas distribution. We will also try to study possible effects on the durability of the detector due to high temperature operation. Taking advantage of the fact that the system will not be used in the next data collection periods, the RPC-TOF-FD will be disassembled from the spectrometer and reassembled in a hangar to perform these studies. Finally, some aspects of the gas installation still need to be completed.
- Finalize the calibration of the RPC-TOF-FD.
- Finalize the construction of the spare module for RPC-TOD-FD.
- Remount the RPC-TOF-W sector.

In general, due to the completion of the RPC-TOF-FD and the present financial situation, the group will keep a low profile.

Medium-term (3-5 years) prospects

While the human resources specifically allocated to HADES activities are currently very low, it should be taken into account that part of the work is supported by the RPC R&D group together with LIP infrastructures DL and MW.

As mentioned, at this time group activities are limited to the development of RPCs and MDCs. We do not exclude the possibility of embracing activities related to data analysis again in the future, but this is not a priority at this time.

The medium term prospect for the next years are focused in our main two lines:

- Optimize, prepare for production beam times and operate the HADES RPC-TOF-W and the RPC-TOF-FD.
- Continue the R&D of the spectrometer tracking system aiming at developing a design able to operate at the beam energies and intensities expected in FAIR.

SWOT Analysis

Strengths & opportunities

- The expertise of the team on the construction of RPCs-based detector allowed us to build a detector able to run within specifications and flawlessly during all campaigns.
- The performance and reliability demonstrated by the RPC-TOF-W and RPC-TOF-FD are a good recommendation letter for other experiments.
- The RPC-TOF-FD has demonstrated the viability of increasing the count rate capability of an RPC detector by increasing the operating temperature.

Weaknesses & threats

- The smallness of the team and the commitments of its members with other projects.
- The lack of funding may strongly compromise all the group activities.
- The loss of the data analysis component weakens the group.
- Uo to now, it has not been possible to recruit colleagues willing to work on physics analysis of the HADES data.

Publications

1 Article in international journal (with direct contribution from team)

- A. Blanco et al.: *"Improving count rate capability of timing RPCs by increasing the detector working temperature"*, NIMA 1045, 2023

Presentations

1 Oral presentation(s) in international conference(s)

- Alberto Blanco Castro, Joao Pedro De Carvalho Saraiva, Luis Lopes, Paulo Fonte: *"The new HADES ToF Forward Detector "*, 2022-09-26, XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, 26–30 Sept 2022

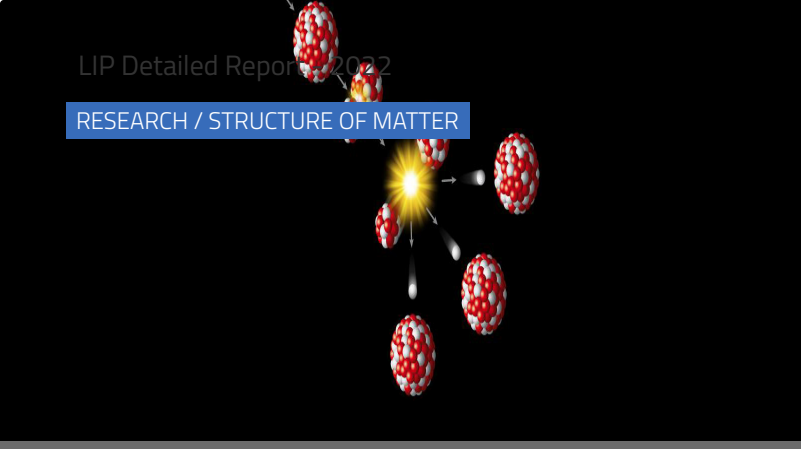
1 Poster presentation(s) in international conference(s)

- Alberto Blanco: *"Improving count rate capability of timing RPCs by increasing the detector working temperature"*, 2022-05-22, PM2021 - 15th Pisa Meeting on Advanced Detectors - Edition 2022, May 22-28, 2022, La Biodola - Isola d'Elba (Italy)

Organized Events

1 Collaboration Meeting

- *"HADES Collaboration Meeting XLIII"*, [Collab-Meet] Coimbra, 2022-09-19 to 2022-09-23



NUC-RIA

Nuclear Reactions, Instrumentation and Astrophysics

Principal Investigator:
Daniel Galaviz (80)

6 ***Researcher(s):***
Alberto Blanco (25), Jorge Sampaio (40), José Pires Marques (80), Luis Peralta (45), Pamela Teubig (76), Paulo Velho (80)

2 ***Technician(s):***
João Saraiva (15), Luís Lopes (15)

5 ***PhD Student(s):***
Carina Coelho (28), Elisabet Galiana (100), Francisco Barba (100), Manuel Xarepe (100), Ricardo Silva (100)

6 ***Master Student(s):***
Carolina Felgueiras (38), Diogo Miguel (33), João Jantarada (100), Lia Pereira (25), Rita Pestana (50), Tomás Correia Sousa (100)

6 ***Undergraduated Student(s) and Trainee(s):***
José Afonso, Madalena Gamboa, Margarida Paulino, Raquel Nunes, Ricardo Pires, Özgür Özer

3 ***External collaborator(s):***
Ana Isabel Henriques, Francisco Fernandez, Luis Acosta

Total FTE:
12.3 (PhD 4.3)

Articles in international journals:	**9** Direct contribution
National journals:	**1** Article
Notes:	**4** LIP Students notes
International conferences:	**5** Oral presentations
National conferences:	**1** Oral presentation
Advanced training events:	**1** Oral presentation
Collaboration Meetings:	**2** Oral presentations
Completed theses:	**1** MSc

Executive summary

The Nuclear Reaction, Instrumentation and Astrophysic (NUC-RIA) group at LIP develops research in topics related to fundamental studies of nuclear reactions, nuclear instrumentation, and studies related to the understanding on the formation of elements in the universe. After a year of growth in terms of research lines and human resources, 2022 was the year to better define and consolidate the scope of the various topics, We can clearly state that this has been achieved in the activities developed within the various research lines:

- Consolidation at R3B/FAIR: In May 2022, the LIP group installed in the R3B experimental setup a timing-RPC detector to measure with high precision the momentum of relativistic protons emitted in reactions on exotic nuclei on a liquid hydrogen target. The campaign was a joint effort with the LIP RPC R&D group. The installation, commissioning and operation of the detector were achieved in less than 6 months, exhibiting an excellent performance. The LIP NUC-RIA group has been part of the R3B experiment at GSI for several years, but up to now with rather lateral participation. This work was driven in the framework of the PhD Thesis of Manuel Xarepe, starting now his second year.
- Execution of experiment IS698 and consolidation within ISOLDE: Lead by our group, experiment IS698 run for eight days at the HIE-ISOLDE laboratory, measuring for the first time a complete angular distribution for the elastic scattering process of alpha particles on unstable isotopes. Francisco Barba started his PhD program in 2022 and will analyze the collected data. We aim to continue expanding and exploring this reseach line at ISOLDE in the coming years.
- Progress made in atomic physics and Kilonova through close collaboration with the GSI-TNA group: This line of work included large scale calculations of atomic data and in-depth study of the opacity of heavy r-process elements. An exploratory project was approved by FCT, and Ricardo Ferreira da Silva started his PhD Thesis on the topic. One published article and several contributions to national and international conferences complete the 2022 outcomes.
- Integration in EUROLABS: The European Nuclear Physics laboratories consortium EUROLABS is an Infrastructure Program of the EU. The thermal evaporator managed by the NUC-RIA group for the manufacturing of thin films for nuclear reaction experiments has been included as participant facility in the sub-task devoted to support to target production. The participation in the consortium should allow for the involvement in future collaborations through the production of thin films over the upcoming years.

The priority given to these activities has put on hold other research topics of the group, such as the modeling of explosive nucleosynthesis or the execution of low-energy experiments, which nevertheless remain present as part of the research goals of the group for the next few years. Overall, the NUC-RIA group had a productive and successful year, opening the door for a 2023 full of expectations and work ahead in a well-defined set of research topics that will be further consolidated in the years to come.

Funding

PI (Co-PI)	Sources	Amount	Dates	Project / Description
Daniel Galaviz (Alberto Blanco)	FCT	49.874 €	2021-10-15 to 2023-04-14	EXPL/FIS-NUC/0364/2021 / SCORE - Short range CORelations on Exotic nuclei at R3B/FAIR using tRPCs
Daniel Galaviz (A.M. Sanchez-Benitez)	FCT	20.000 €	2022-04-01 to 2024-03-31	CERN/FIS-PAR/0009/2021 / RENASCER - Estudos de reações nucleares para Astrofísica Nuclear na instalação ISOLDE do CERN
Jorge Sampaio (José Pires Marques)	FCT	46.485 €	2023-01-01 to 2024-06-30	2022.06730.PTDC / Parâmetros atómicos para modelação de quilonovas

NUC-RIA

Overview

The NUC-RIA develops research in the fields of atomic and nuclear physics through the modeling and measurement of nuclear reactions. The primary focus falls in the following lines of work:

- High-energy reactions and data analysis on exotic nuclei at R3B/FAIR;
- Low-energy reactions on stable and unstable nuclei for Nuclear Astrophysics;
- Atomic Astrophysics for the study of kilonovae and the origin of heavy elements.

The group maintains a strong emphasis on experimental work and is present in low- and high-energy nuclear radioactive beam facilities, mainly in Europe. In the field of Atomic and Nuclear Astrophysics, the combination of experimental and theoretical expertise has considerably strengthened our contribution.

The group, led by Daniel Galaviz, is mostly based at the Faculty of Sciences of the University of Lisbon, where direct contact with students at all levels has a high potential for attraction and interaction. The core team presently consists of 5 PhD researchers, 5 PhD students, and 6 Master Students.

Assessment of the past year: objectives vs. achievements

Overall we can state that the majority of our goals presented in the previous year's report were attained, in some cases with higher performance than foreseen. We emphasize the following aspects:

- **Experimental campaign in R3B/FAIR:** As anticipated, during 2022 a timing RPC detector (built by the LIP RPC R&D group in Coimbra) was installed the R3B experimental setup. The campaign for the measurement of reactions of exotic nuclei on a proton target took place during May/June 2022. Several members of our group actively participated in the preparation and execution of the experiments. We highlight the extensive contributions of the students Manuel Xarepe (PhD) and Tomás Sousa (MSc), who presented the results of their work in the two collaboration meetings of the year. Manuel Xarepe also presented the project in the RPC2022 Workshop at CERN, leading to the first publication of the group on this topic (presently under review).
- **ISOLDE experiment IS698:** Our approved experiment to measure the scattering of alpha particles on exotic nuclei for the first time was selected for beam time in September 2022 (this was quite unexpected, considering the back-lock of about 2000 experimental shifts at ISOLDE). The experimental campaign was a success, demonstating the proposed methodology and opening the door for future experimental campaigns. Data are now being analyzed by Francisco Barba, who in 2022 defended his MSc in a related topic and enrolled in the PhD program by the end of last year. Daniel Galaviz presented the preliminary results of this measurement to the ISOLDE collaboration in December 2022.
- **Atomic Physics and Kilonova:** Great progress has been in this topic, in close collaboration with the GSI-TNA group. The efforts were put in large scale calculations of atomic data required for the modeling of kilonovae, but also in the detailed study of the opacity of heavy r-process elements and its relation with different atomic properties. In the NUC-RIA side, The work was developed moslty by PhD student Ricardo Ferreira da Silva and researchers Jorge Sampaio and José Marques. This resulted in the publication of one article (with another one in progress), and in oral contributions to one national and three international conferences. In addition, a line of financial support for these efforts was approved by FCT: a recently approved exploratory research project, and a PhD grant awarded to R. F. Silva.
- **Target evaporation laboratory:** This year, the group as joined the consortium EUROpean Laboratories for Accelerator Based Science project (EUROLABS) as a supporting group for the production and characterization of targets to be used in nuclear reaction experiments. This is a great achievement for this rather small facility that complements the work done in larger scale facilities. In the meantime, several students have joined this laboratory under the supervision of Pamela Teubig, leading to the production of several targets manufactured from natural composition materials (such as Ag, Al, CaF_2, AgCl, Sn and Pb) as well as from highly enriched materials such as ^{208}Pb or ^{118}Sn.
- **Low-energy nuclear reactions:** While experimental work on the measurement of (p,gamma) reactions using the activation technique via the measurement of X-ray yields was not pushed forward last year, a new line of research has developed connected to theoretical work on the modeling of nuclear reaction networks. The latter is primarily concerned with the modelling of p-process nucleosynthesis and as been developed by MSc student Afonso Jantarada.
- **Outreach:** As planned, we have contributed to the IPPOG Masterclasses at FCUL, which in 2022 took place online. Furthemore, NUC-RIA was the group that contibuted with the highest number of projects in the LIP Summer Internship Program. A total of 6 projects were developed by 10 students, mentored by seniors and students of the group.

Lines of work and objectives for next year

The group now has consolidated lines of work that demand continuity in the short and medium terms. In the following, we depict the current plans for the next year:

- **Preparing the future at R3B:** Due to energy crisis in Europe over the past year, the experimental campaign at the FAIR laboratory was completely postponed to 2024. There will be nevertheless some "engineering runs" during the fall of 2023, where we will verify the status of the RPC detector, preparing the system for its inclusion in the various experimental proposals approved in the previous FAIR-PAC (the use of the RPC is considered in four approved experiments). We will also start exploring the possibility of the permanent use of the RPC technology in the R3B setup to detect and characterize the emitted protons from nuclear reactions in inverse kinematics. This will be the topic of the MSc thesis of Diogo Miguel, who recently joined the research group. During 2023 the MSc Thesis of Tomás Sousa, on the analysis of high energy signals on the electromagnetic calorimeter CALIFA will be concluded. Last but not least, Manuel Xarepe will continue analyzing the data from experiment S509, studying the nature of nucleon short range correlations in radioactive isotopes in the framework of his PhD thesis.
- **Preparing the future at ISOLDE:** While Francisco Barba will advance in the analysis of the data measured in the experimental campaign IS698, we will prepare the way for future measurements at the same facility using a similar approach. It is our goal to lead an international collaboration to propose exploring further unstable regions of the nuclear chart and provide additional information on nuclear properties of isotopes involved in thermonuclear explosions in massive stars. This will be achieved through the preparation and submission of an additional experimental proposal to the INTC committee at CERN. In addition, we expect that a similar experimental approach will be re-scheduled at the LNS/INFN laboratory in Catania during 2023. Another MSc student, Raquel Nunes, has recently joined the group and could use this opportunity as part of her thesis work.
- **Atomic Physics and Kilonova**: The increasingly high demand of atomic data for the modeling of kilonovae makes this line particularly relevant in the short term. While one publication is planned to be submitted in the beginning of the year, additional work is planned, where we highlight the development of a systematic way to provide large-scale calculations in good agreement with experimental available data. Also, in line with the recently approved exploratory research project ATOMIK, we plan to provide calculations for all relevant lanthanide and actinide charged states. The main goal is to provide opacity calculations not only in LTE, but also with the intention to study beyond-LTE effects for which reliable atomic data is still lacking in the community.
- **Low-energy nuclear reactions:** This year we intend to resume the research program focused on measuring low-energy reactions for nuclear astrophysics applications. For that we intend to take advantage of the ChETEC-Infra network of infrastructures for the planning of research proposals in European laboratories. In addition, and in the context of Ricardo Pires and Margarida Paulino's MSc Thesis, low-energy (p,gamma) measurements are expected to continue in the CTN/IST campus. The study of reaction network calculations for nucleosynthesis is expected to see a continued growth, not only with the defense of MSc candidate Afonso Jantarada in the beginning of the year, but also through his proposed follow-up study utilizing reaction network codes to quantify the effects of measured reactions on nucleosynthesis simulations.
- **Target production:** We are dedicated to maintaining the production and characterization of high-quality targets within the context of our recent participation in the EUROLABS consortium. Multiple targets are currently being planned and developed for ongoing experiments in 2023. Among them we can include the production of targets for experiments being conducted at CMAM in Spain, and targets for reaction cross-section studies at CTN-IST. Additionally, we are preparing a highly enriched ^{208}Pb target for a nuclear experiment to be conducted at Notre Dame laboratory in the USA. Participation in the consortium should provide for future partnerships involving the production of these thin films in the coming years.
- **Outreach:** Our regular contribution to the organization of IPPOG Masterclass, to be held in FCUL this year, is already planned. Furthermore, we aim to continue our involvement in the LIP Summer Internship Program by focusing on enhancing the quality of the internships offered, while striving to maintain the number of projects offered as we did the previous year.

In order to achieve these goals, it is crucial and a priority to attract a group of highly-qualified researchers, including PhD students and postdocs, in the years ahead.

Medium-term (3-5 years) prospects

The previous years, the medium-term strategy was always presented in a perspective of intentions. This year, we truly believe that the strategy has a solid basis for the medium-term growth of the group and the field within LIP. The strategic highlights can be outlined as follows:

- **Full inclusion in R3B at FAIR:** In the medium term, we aim at consolidating the presence in this experiment covering most of the relevant aspects for a strong presence, namely students, researchers, detector instruments and research proposals. The perspective of the inclusion of one (or more) RPCs in the setup opens a window of opportunity for consolidating our presence in one of the flagship facilities in nuclear science in Europe and the world.
- **Experimental program at ISOLDE**: Following the successful experimental campaign, we will devote great effort to build a strong international collaboration to actively be part of this facility to investigate nuclear reactions with radioactive isotopes and its implications in astrophysical environments. Aligned with LIP's strategy of strengthen the Portuguese presence at CERN, we identify this research path as a growth line in the years to come.
- **Atomic Physics and Kilonova:** This line of research has arrived to stay. In the coming years, we intend to consolidate our contribution to the field by expanding the current theoretical calculations to a larger scale, and by collaborating with other theoretical and experimental groups towards the creation of a new database that encompasses a comprehensive range of atomic properties, needed in various astrophysical applications, including kilonova events.

Furthermore, the group will actively seek for funds at both national and European levels to keep the various research activities. The participation in European consortia and involvement in multi-national funding applications will be a task to cover by the members of the group. The participation in the EUROLABS consortium (2022-2026) will be the first effective contribution in the medium-term, although further involvement will be sought.

SWOT Analysis

Strengths

- Strong international collaboration experience
- Expertise in instrumentation, data analysis, particle transport simulations, and nuclear astrophysics
- Proven track record of participation in experiments at various radioactive and stable beam accelerator institutes
- Combination of experimental and theoretical work

Weaknesses

- Limited funding, which may prevent the group from effectively contribute to the construction of new detection systems in international collaborations
- Limited number of senior researchers, with strong teaching commitments
- Lack of postdoctoral researchers in the group

Opportunities

- International participation offers visibility and potential to attract young researchers
- Opportunities to expand current collaborations to other institutes
- Participation in EUROLabs, ChETEC-Infra, and a potential COST action in Nuclear Astrophysics offers growth opportunitie

Threats

- Inability to effectively participate in next-generation facilities like FAIR or ISOLDE may endanger future involvement
- Lack of funding may be an obstacle to student retention and recruitment of senior researchers, hindering group growth and sustainability.

NUC-RIA

Publications

9 Articles in international journals (with direct contribution from team)

- *"Isotopic cross sections of fragmentation residues produced by light projectiles on carbon near 400A MeV"*, J. M. Boillos, D. Cortina-Gil, J. Benlliure, et al. (R3B collaboration), Phys. Rev. C 105, 014611 (2022)
- *"Structure Calculations in Nd III and U III Relevant for Kilonovae Modelling"*, Ricardo F. Silva, Jorge M. Sampaio, Pedro Amaro, Andreas Flörs, Gabriel Martínez-Pinedo, and José P. Marques, Atoms2022,10,18
- *"Structure of single KL0–, double KL1–, and triple KL2–ionization in Mg, Al, and Si targets induced by photons, and their absorption spectra"*, Y. Ménesguen, M.-C. Lépy, Y. Ito, M. Yamashita, S. Fukushima, T. Tochio, M. Polasik, K. Slabkowska,L. Syrockif, P. Indelicatog, J. P. Gomilsekh, J. P. Marques, J.M.Sampaio, J. Machado, P. Amaro, M. Guerra, J. P. Santos, and F. Parente, Rad. Phys. Chem. 194, 110048 (2022)
- *"Unveiling the two-proton halo character of 17Ne: Exclusive measurement of quasi-free proton-knockout reactions"*, C. Lehr, F. Wamers, F.Aksouh, et al., Phys. Lett. B 827, 136957 (2022)
- *"Experimental and theoretical approaches for determining the K-shell fluorescence yield of carbon"*, Philipp Hönicke, Rainer Unterumsberger, Nils Wauschkuhn, Burkhard Beckhoff, Markus Krämer, Paul Indelicato, Jorge Sampaio, José Pires Marques, Mauro Guerra, Fernando Parente, and José Paulo Santos, Rad. Phys. Chem. 202, 110501 (2023)
- *"L-shell fluorescence yield for heavy elements with 80≤Z≤96"*, K. Meddouh, S. Daoudi, A. Kahoul, J.M. Sampaio, J.P. Marques, F. Parente, N. Kup Aylikci, V. Aylikci, Y. Kasri, A. Hamidani, Rad. Phys. Chem. 202, 110481 (2023)
- *"K- and L-shell theoretical fluorescence yields for the Fe isonuclear sequence"*, Daniel Pinheiro, André Fernandes, César Godinho, Jorge Machado, Filipe Grilo, Luís Sustelo, Jorge M. Sampaio, Pedro Amaro, Roberta G. Leitão, José P. Marques, Fernando Parente, Paul Indelicato, Miguel de Avillez, José Paulo Santos, Mauro Guerra, Rad. Phys. Chem. 203, 110594 (2023)
- *"Semi-empirical and empirical calculation of Kβ/Kα intensity ratios for Low-Z Elements"*, A. Hamidani, A. Kahoul, S. Daoudi, J.M. Sampaio, J.P. Marques, F. Parente, K. Meddouh, N. Kup Aylikci, V. Aylikci, Y. Kasri, At. Nucl. Data Tables 149, 101549 (2023)
- *"Independently Optimized Orbital Sets in GRASP – The Case of Hyperfine Structure in Li I"*, Y. Li, P. Jönsson, M. Godefroid, G. Gaigalas, J. Bieron, J. P. Marques, P. Indelicato, and C. Chen, Atoms 2023, 11, 4

1 Article(s) in national journals

- *"Medição de Processos de Colisão Eletrónica em Fe XVII de Interesse Astrofísico"*, F. Grilo, P. Amaro, C. Shah, J. P. Marques, J. P. Santos, J. R. Crespo López-Urrutia, Revista Medições e Ensaios (Sociedade Portuguesa de Metrologia), nº16, 3 (2022).

4 LIP Students Notes

- *"nRPC simulation with TOPAS"*, Carolina Felgueiras, LIP-STUDENTS-22-13
- *"Target preparation at FCUL"*, Margarida Paulino, Raquel Nunes, LIP-STUDENTS-22-22
- *"Radiation ""bombs"" in amyloids"*, Hannah Scharff, Maria Teixeira Rebouta, LIP-STUDENTS-22-23
- *"Measuring The Sky"*, Özgür Özer, LIP-STUDENTS-22-25

Presentations

5 Oral presentations in international conferences

- J. P. Marques: *"Biomedical and astrophysical applications of atomic parameters"*, 2022-09-22, "IBER2022 - XVI Joint Meeting on Atomic and Molecular Physics", Málaga, Spain, September 21-23, 2022., Málaga, Spain
- Ricardo Ferreira da Silva, Andreas Floers, Gerrit Leck, Pedro Amaro,Jorge Miguel Sampaio, Gabriel Martinez-Pinedo, José P. Marques: *"Calculation of Atomic Inputs for Probing r-Process in Kilonovae "*, 2022-09-22, IBER 2022 – XVI Iberian Joint Meeting On Atomic And Molecular Physics , Málaga (Spain)
- Manuel Xarepe: *"Resistive Plate Chambers for Precise Measurement of High-Momentum Protons in Short Range Correlations"*, 2022-09-26, XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, 26–30 Sept 2022
- Ricardo Ferreira da Silva, Andreas Floers, Gerrit Leck, Pedro Amaro,Jorge Miguel Sampaio, Gabriel Martinez-Pinedo, José P. Marques: *"Characterization of relevant atomic inputs for kilonovae Modelling"*, 2022-09-26, 12th ICAMDATA International Conference on Atomic and Molecular Data and Their Applications, Angevin Castle Mola di Bari (Italy) (remote participation)
- Andreas Floers, Gerrit Leck, Pedro Amaro, Jorge Miguel Sampaio, Gabriel Martínez-Pinedo, José Pires Marques: *"Calculation of atomic inputs of r-process elements for kilonova modelling"*, 2022-11-30, Kilonova: Multimessenger and Multiphysics, 774. WE-Heraeus-Seminar, Physikzentrum Bad Honnef, Germany

1 Presentation(s) in national conference(s)

- Jorge Sampaio, Ricardo F. Silva, José Pires Marques: *"Large-Scale Atomic Structure Calculations in Kilonovae Modelling"*, 2022-09-09, 23º Conferência Nacional de Física, Faculdade de Ciências da Universidade do Porto

1 Presentation(s) in advanced training event(s)

- Jorge Sampaio: *"Atomic Inputs for kilonovae modelling"*, 2022-07-27, High Performance Computing in Astrophysics and Atomic Physics Summer School, FCT-UNL

Theses

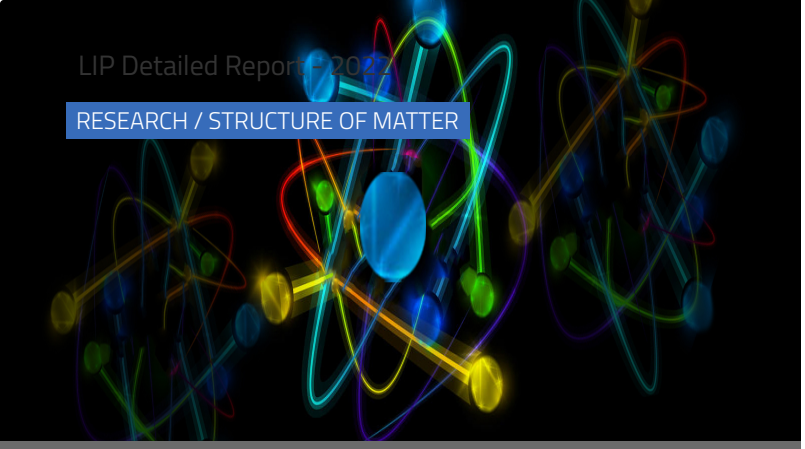
5 PhD

- Elisabet Galiana: *"Analysis and simulation of (p,gamma) and PIGE low energy reactions: An ENSARRoot developmen"*, 2018-01-01, (ongoing), FCUL, Supervisor(s): Daniel Galaviz
- Carina Coelho: *"The effects of proton therapy on protein self-organization: potential benefits for neurodegenerative disorders"*, 2021-10-01, (ongoing), FCUL, Supervisor(s): Daniel Galaviz, Federico Herrera and Sílvia Viñals
- Manuel Xarepe: *"Measurements of Short Range Correlations on Exotic Nuclei at R3B using TRPCs"*, 2021-09-01, (ongoing), FCUL, Supervisor(s): Daniel Galaviz, Alberto Blanco

- Ricardo Silva: *"Atomic inputs for probing the r-process in kilonovae"*, 2022-10-01, (ongoing), FCUL, Supervisor(s): José Pires Marques, Jorge Sampaio
- Francisco Barba: *"Studying the origin of the elements with radioactive ions at ISOLDE/CERN"* (ongoing) FCUL - Supervisor: Daniel Galaviz

7 Master

- Francisco Barba: *"Characterization of thin silicon strip detectors for nuclear experiments"*, 2020-09-01 / 2022-04-22, (finished), FCUL, Supervisor(s): Daniel Galaviz,
- Tomás Correia Sousa: *"Characterization of CsI(Tl) Crystals and Implementation of tools for the CALIFA calorimeter at FAIR "*, 2021-10-01, (ongoing), FCUL, Supervisor(s): Daniel Galaviz,
- Lia Pereira: *"Modelling protein amyloid structures and observing the effects of radiation using the GEANT4-DNA toolkit"*, 2021-10-04 , (ongoing), FCUL, Supervisor(s): Daniel Galaviz,
- João Jantarada: *"Simulation of a p-process in a Supernova Explosion using the NucNet Tools framework."*, 2021-10-01 , (ongoing), FCUL, Supervisor(s): Daniel Galaviz,
- Rita Pestana: *"Development of a standard methodology for online dose calculation in air "*, 2021-10-01, (ongoing), FCUL, Supervisor(s): Daniel Galaviz,
- Diogo Miguel: *"Simulations of an RPC detector in combination with CALIFA at R3B"* (ongoing) FCUL - Supervisor: Daniel Galaviz
- Carolina Felgueiras: *"Simulations and benchmark of a fast neutron detector for nuclear astrophysics "*, 2022-10-01 , (ongoing), FCUL, Supervisor(s): Daniel Galaviz,



NPSTRONG

Nuclear Physics and Strong Interaction Group

Principal Investigator:
Teresa Peña (30)

4 ***Researcher(s):***
Alfred Stadler (70), Ana Arriaga (25), Elmar Biernat (40), Gernot Eichmann (70)

3 ***PhD Student(s):***
André Torcato (70), Eduardo Ferreira (80), Raúl Torres (86)

1 ***Master Student(s):***
André Nunes (11)

2 ***Undergraduated Student(s) and Trainee(s):***
João Galupa, Pau Petit Rosas

2 ***External collaborator(s):***
Paul Wallbott , Walter Heupel

Total FTE:
4.8 (PhD 2.4)

Articles in international journals:	**3** Direct contribution
International conferences:	**9** Oral presentations
Nat.& Internat. meetings:	**2** Oral presentations

Executive summary

NPStrong, the Nuclear Physics and Strong Interaction Group, joined LIP in 2020. Its members share common research interests in nuclear and hadron physics. Our research aims at a theoretical understanding of the consequences of the first principles of QCD at the interface of hadron and nuclear physics.

We work on a variety of topics addressing nonperturbative phenomena in quantum field theories with computational methods, in particular Quantum Chromodynamics (QCD). These topics include the internal structure of mesons and baryons, their interactions with photons, the production mechanisms and properties of exotic hadrons such as quark-gluon hybrids and glueballs, and the nature of tetraquarks and pentaquarks, which are not yet understood from first principles, and whose evidence challenges our understanding of the strong force. Fundamental and still open questions behind these activities are the origin of confinement of quarks in hadrons and nuclei, the origin of mass, and the properties of matter in extreme conditions as in neutron stars.

To describe bound systems of quarks and gluons, we use nonperturbative functional methods such as Dyson-Schwinger and Bethe-Salpeter equations. These methods are complementary to lattice QCD simulations and provide ab-initio solutions for QCD's correlation functions, where the soft and hard scales are intertwined by nonperturbative integral equations. Such correlation functions subsequently enter in the calculation of hadron properties and allow us to make predictions for hadronic observables.

The research activities of the group are internationally recognized and have been part of collaborations and networking activities including the Universities of Heidelberg and Giessen (Germany), Graz (Austria), Cruzeiro do Sul (Sao Paulo, Brazil), the Jefferson Laboratory and Iowa State University (USA). Two members of the group were elected associate members of HFHF, Helmholtz Forschungsakademie Hesse fur Fair, a German think tank for FAIR physics. One is member of the International Light Cone Advisory Committee.

In 2022 NPStrong not only continued ongoing research in theoretical nuclear and hadron physics at LIP, but we have been exploring new research directions. The scientific achievement highlights in the year 2022 were:

- Heavy baryon spectrum using functional methods and within a quark-diquark approach model.
- Hadron properties on the light front by employing contour deformations in the complex plane for calculations with functional methods.
- Dyson-Schwinger equations in Landau-gauge Yang-Mills theory, providing evidence that mass generation in the transverse sector is triggered by longitudinal massless poles.
- Spectrum of heavy-light pentaquarks in view of the LHCb pentaquarks.

The two master students of group in the previous year were successful in obtaining PhD grants from the competitive funding program for all areas of Physics. Student Eduardo Ferreira was awarded the McCartor Fellowship Award. The international prestige and high potential of one of our non-permanent senior staff members implied that he was hired by the University of Graz. One of the PhD students has followed the supervisor for a PhD in Graz.

Sources of funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Gernot Eichmann	FCT	22.382 €	2017-04-01 to 2022-03-31	IF/00898/2015 / Expl. 2015_VL - IF/00898/2015_Multiquarks
Alfred Stadler (Gernot Eichmann)	FCT	70.000 €	2022-03-15 to 2024-03-14	CERN/FIS-PAR/0023/2021 / Nuclear Physics and Strong Interaction Group

NPStrong

Overview

NPStrong, the Nuclear Physics and Strong Interaction Group, joined LIP in 2020. Its members share common research interests in nuclear and hadron physics. We work on a variety of topics addressing nonperturbative phenomena in quantum field theories with computational methods, in particular Quantum Chromodynamics (QCD). These topics include the internal structure of mesons and baryons, their interactions with photons, the production mechanisms and properties of exotic hadrons such as quark-gluon hybrids and glueballs, and the nature of tetraquarks and pentaquarks, which are not yet understood from first principles, and whose evidence challenges our understanding of the strong force.

In 2022, our work focused on the following research topics:

- Dynamical chiral symmetry breaking, confinement and QCD's elementary correlation functions.
- Bound states and resonances in non-perturbative quantum field theories.
- Spectroscopy and structure of mesons and baryons within QCD functional methods.
- Multiquark systems using QCD functional methods.
- Ab-initio calculations in the gluon sector towards full QCD (gluonic massive Yang-Mills regime and massless decoupling solutions).

The group NPStrong currently consisted till the end of September 2022 of five senior members (three of them permanent), three PhD students and one Master student. Two undergraduate trainees were supervised within the group in the framework of the LIP Internship Programme.

The international prestige and high potential of one of our non-permanent senior staff members implied that he was hired by the University of Graz, and we are now four senior members. Also one of the PhD students is no longer part of group, as he has followed the supervisor for a PhD in Graz.

Assessment of the past year: objectives vs. achievements

In 2022 NPStrong continued to consolidate its research in theoretical nuclear and hadron physics at LIP. We have also been exploring new research directions.

The two master students of group in the previous year were successful in obtaining PhD grants from the competitive funding program for all areas of Physics. One of the students was awarded the McCartor Fellowship Award.

The scientific achievement highlights in the year 2022 were:

- Heavy baryon spectrum using functional methods and within a quark-diquark approach model, extending previous calculations in the light sector to the charm sector.
- Hadron properties on the light front by employing contour deformations in the complex plane for calculations with functional methods. One of our students received the McCartor Fellowship Award for this work., as mentioned above.
- Dyson-Schwinger equations in Landau-gauge Yang-Mills theory, providing evidence that mass generation in the transverse sector is triggered by longitudinal massless poles.
- Spectrum of heavy-light pentaquarks in view of the LHCb pentaquarks, including their pole positions in the complex momentum plane, computing all couplings in the system.

These scientific achievements match the objectives previously stated for the year.

-We were part of the organization of two International meetings::

- International Conference on the Structure of Baryons, Baryons 2022, Seville.
- Doctoral Training Program 2022 Hadron Physics with Functional Methods, Trento, Italy.

-Gernot Eichmann was convener of the NSTAR2022 Conference in Genova

We delivered 11 invited talks at International Meetings. The group published 3 papers:

Lines of work and objectives for next year

We aim to continue providing high-impact results with international recognition and maintaining close ties to experimental efforts at LHCb, ALICE, COMPASS, AMBER, FAIR, Jefferson Lab and the future Electron

Ion Collider (EIC). To this end, we will deepen our well-established lines of research and follow up on the new lines of research that we have begun to explore:

Parton distributions: Our new method to obtain light-front wave functions using contour deformations has opened the door for the calculation of parton distributions such as PDFs, TMDs and GPDs. We are planning to apply the method to the meson sector. This work will create conditions for synergistic connections to the LIP group that is part of the AMBER@CERN collaboration.

Multiquarks: Self-consistent calculations of five- and six-quark systems will generalize our existing multiquark studies towards a first description of light nuclei within functional methods. One of the main questions is how the inner clusters of multiquark systems, either compact or molecular-like, can be understood from QCD in terms of quarks and gluons. This is relevant given the recent LHCb findings. Extension to a six-quark state as the deuteron will also be explored by a master project.

Ab-initio calculations in QCD: A major goal is to extend our newly established ab-initio calculations in the gluon sector towards full QCD. This will serve as the starting point for genuine ab-initio calculations of hadron properties, which should significantly elevate the state of the art in the theoretical calculation of hadron observables. One of the PhD students is participating in this task.

Meson spectroscopy: Our final goal is a comprehensive description of meson properties covering the light and the heavy quark sector in a unified and consistent way.

Baryon spectroscopy and structure: Based on our new calculations of the heavy-baryon spectrum, the goal is to extend our previous studies to understand the spectrum and structure of hyperons, including their spacelike and timelike form factors, which is part of the pillars of the FAIR-GSI program.

Medium-term (3-5 years) prospects

Hadron spectroscopy: Our unique expertise in functional methods, especially also for 3- and 4-body systems, enables us to extend our portfolio to heavy-light pentaquarks and other exotic hadrons.

Hadron structure: In view of the forthcoming EIC and Amber@CERN, there are efforts, especially in lattice QCD, to calculate hadron structure observables from first principles, which encode the spin and orbital momentum of hadrons as well as their mass decomposition. Similar advances can be made using functional methods and our group could take the lead role in these efforts.

From QCD to nuclear physics: The strong interaction binds quarks and gluons to hadrons but also protons and neutrons to nuclei. An important question is how short-range nuclear correlations emerge microscopically and induce the behavior at the level of nuclei. High-momentum nucleons are relevant for neutron-rich systems and neutron stars, the dissociation of Borromean drip-line nuclei, capture reactions in nuclear astrophysics, and the EMC effect describing the change of parton distributions inside nuclei.

SWOT Analysis

Strengths

Unique expertise in functional methods to calculate hadron properties, especially multiquark systems, from non-perturbative QCD.
Use of complementary theoretical toolkits to test model independence.
International recognition and collaborations.

Opportunities

NPStrong naturally connects with the Pheno, Partons and QCD, NUC-RIA groups at LIP and can create new synergies.
Astrophysical data reinforce interdisciplinary links between astroparticle, nuclear and particle physics; the NPStrong expertise at LIP is ideal for their synergistic combination.

Weaknesses

Reduced dimension of the group.

Threats

Lack of funding threatens the group's activities.
Lack of permanent positions creates instability and limit long term planning.

NPStrong

Publications

3 Articles in international journals (with direct contribution from team)

- Gernot Eichmann, Jan M. Pawlowski (selected for Editor's choice): *"Studying mass generation for gluons"*, SciPost Phys.Proc. 6 (2022) 018
- Gernot Eichmann, Eduardo Ferreira, Alfred Stadler (selected for Editor's Choice): *"Going to the light front with contour deformations"*, Phys.Rev.D 105 (2022) 3, 034009
- Gernot Eichmann: *"Theory introduction to baryon spectroscopy"*, Few-Body Systems volume 63, Article number: 57 (2022)

Presentations

9 Oral presentations in international conferences

- Gernot Eichmann: *"Going to the light front with contour deformations"*, 2022-06-15, FunQCD22, Valencia
- Teresa Peña: *"Analysis of Baryon Electromagnetic Transition Form Factors"*, 2022-09-09, Quarks and Nuclear Physics (QNP2022),
- Gernot Eichmann: *"Hadron structure and spectroscopy with functional methods"*, 2022-09-09, Quarks and Nuclear Physics (QNP2022),
- Eduardo Ferreira: *"Going to the light front with contour deformations"*, 2022-09-19, LIGHT CONE 2022, (Online)
- Teresa Peña: *"(Transition) Form Factors of Baryons"*, 2022-10-17, NSTAR 2022 - 13th International Workshop on the Physics of Excited Nucleons , Santa Margherita Ligure, Genova
- Eduardo Ferreira: *"Going to the light-front with contour deformations"*, 2022-11-07, Baryons 2022 - International Conference on the Structure of Baryons,
- Gernot Eichmann: *" Hadron structure and spectroscopy with functional methods"*, 2022-11-09, Baryons 2022 - International Conference on the Structure of Baryons,
- Raúl Torres: *"Pentaquarks in a Bethe-Salpeter approach"*, 2022-11-09, Baryons 2022 - International Conference on the Structure of Baryons,
- André Torcato: *"Heavy baryon spectroscopy in a quark-diquark approach"*, 2022-11-10, Baryons 2022 - International Conference on the Structure of Baryons,

2 Oral presentations in national or international meetings

- Alfred Stadler: *"To the light front with contour deformations"*, 2022-05-13, Perceiving the Emergence of Hadron Mass through AMBER@CERN - VII Workshop, (Online)
- Teresa Peña: *"Analysis of Baryon Transition Electromagnetic Form Factors"*, 2022-09-21, HADES Open Workshop , Coimbra, Portugal

Theses

3 PhD

- Raúl Torres: *"Pentaquark spectroscopy for the LHC"*, 2021-04-01 , (ongoing), IST, Supervisor(s): Gernot Eichmann, Teresa Peña
- Eduardo Ferreira: *"The Partonic Structure of Hadrons"*, 2022-03-01 , (ongoing), IST, Supervisor(s): Gernot Eichmann,
- André Torcato: *"Heavy baryon excitations with functional calculatiosn: Confirming CERN discoveries and predicting new states"*, 2022-09-01 , (ongoing), IST, Supervisor(s): Teresa Peña,

1 Master

- André Nunes: *"The deuteron as a six-quark state in QCD"*, 2022-10-10 , (ongoing), FCUL, Supervisor(s): Ana Arriaga, Gernot Eichmann

[Cosmic rays]

AMS

Auger

SWGO

RESEARCH / COSMIC RAYS

AMS

Collaboration in AMS - Alpha Magnetic Spectrometer

Principal Investigator:
Fernando Barão (55)

3 ***Researcher(s):***
Luisa Arruda (25), Paula Bordalo (70), Sérgio Ramos (70)

1 ***PhD Student(s):***
Miguel Orcinha (100)

3 ***Undergraduated Student(s) and Trainee(s):***
Diogo Lemos, Hanaan Shafi, Rafael Parente

2 ***External collaborator(s):***
Eduardo Bueno, Manbing Li

Total FTE:
3.2 (PhD 2.2)

Articles in international journals:	**2** Direct contribution **1** Indirect contribution
Notes:	**2** LIP Students notes
Advanced Training Events:	**4** Oral presentations **2** Student presentations
Seminars:	**9** Outreach seminars

Executive summary

Since 1998 LIP is part of the broad international collaboration that designed and operates the Alpha Magnetic Spectrometer (AMS). The project had two distinct phases: first a prototype was built and flown aboard the space shuttle in 1998; and a final detector was installed in the international space station (ISS) in May 2011. The experiment is expected to be continue taking data for the entire lifetime of the ISS. Since May 2011, a large set of data have been gathered at a continuous rate of around 45 million events/day, corresponding now to around 215 billion events recorded.

Before the launch of AMS, the LIP group took a leading role in the design, study, simulation and reconstruction activities of the RICH subdetector, aiming at a very precise measurement of particle velocity. In this context, the group is responsible for the development, implementation and maintenance of a set of algorithms for reconstructing the electric charge and velocity of particles using the RICH detector. The group is also involved in studies related to isotopic sensitivity.

Following the launch of AMS in 2011, the group is also involved on data analysis, participating in the AMS detector commissioning, focusing mainly on the RICH detector's velocity and charge measurements and later adding cosmic ray (CR) data analysis to its research efforts. This led to the study of the galactic CR flux with particular emphasis on variability studies related to solar activity. The group already contributed to the area with several publications studying not only the correlation between the sun cycle and the CR flux but also the intrinsic propagation mechanisms present in solar modulation effects.

Over the last few years the group became (more) involved in deuteron/proton separation and isotope flux analysis. Due to their intrinsically different cross-section, isotopes can be used to probe different space depths. Isotope fluxes are thus fundamental for the understanding galactic matter distribution and CR transport mechanisms. The RICH subdetector is a key player in this analysis. Its measurement accuracy enables mass separation capabilities beyond any other detector in space. This makes our group specially well qualified to tackle this task.

Keeping up with this group's long history of making international scientific collaborations, it currently maintains strong connections to the AMS research groups in LPSC - Grenoble, INFN - Perugia and University of Geneva.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Fernando Barão (Luisa Arruda)	FCT	45.000 €	2021-12-01 to 2023-11-30	CERN/FIS-PAR/0007/2021 / Collaboration in the AMS experiment at de ISS for the detecting intermediate energy cosmic rays

AMS

Overview

The main activities in which the group is involved are the following:

1. RICH subdetector

The LIP group is responsible for one of the two sets of reconstruction algorithms implemented in the RICH subdetector of AMS. The algorithms provide measurements of particle velocity and electric charge based on Cherenkov ring patterns. This detector is used in analyses where accurate velocity measurements are required, such as mass separation in isotopic studies.

2. AMS data variability studies

The Sun presents an 11-year activity cycle. Solar activity, varying in a periodic way, affects cosmic ray fluxes arriving at Earth, particularly up to rigidity cutoff values around 40 GV. Flux variations are expected to depend on the particles charge, mass and rigidity, with complex time dependences that provide great insight into the underlying cosmic ray transport mechanism and on solar periodicities. Since 2011 the LIP group is involved in the study of the solar modulation of cosmic rays and in its interpretation under Solar modulation models.

3. Particle identification and isotopic measurements

The group is also involved in data analysis related to particle identification, based on BDT and PDF techniques. Such tools were applied to anti-proton/electron separation and to isotopic identification. Currently, the group's main focus in this topic is on deuteron separation with respect to its closest most abundant species, the proton. This requires accurate characterization of the measurements involved and state-of-the-art data analysis techniques. The group has contributed to the tuning of beryllium (Be) isotope analysis through the optimization of the RICH velocity measurement.

4. AMS POCC activities

The AMS detector monitoring and operation is carried out 24h/24h in the POCC (Payload Operations and Control Center) head-quartered at CERN. LIP team members participate regularly in the POCC activities, performing shifts and acting as on-call experts for the RICH detector.

Assessment of the past year: objectives vs. achievements

Monitoring, characterization and operation of the AMS RICH detector

Velocity measurement of incoming cosmic rays in AMS are done with two independent sub-detectors.

- The Time-of-Flight detector (ToF) is an integral part of the instrument's trigger system and is used for low velocity measurements.
- The Ring-Imaging Cherenkov detector (RICH) provides the most precise velocity measurement available in AMS (0.12% for singly charged particles).

The reconstruction of velocity is performed with two intrinsically different algorithms; the CIEMAT algorithm is based on a hit-by-hit ring reconstruction, while the LIP algorithm relies on a likelihood approach.

As previously mentioned, the RICH detector plays a fundamental role in isotopic separation. Characterising and understanding the factors contributing to systematic biases in velocity measurement is essential. In particular, it is required to monitor how velocity depends on the particle impact point on the radiators, particle inclination, photon ring topology and detection region, as well as possible ageing effects.

In the scope of the collaboration with Geneva University's AMS group and of the Be isotopic analysis work (Jiahui Wei), RICH reconstruction performance was monitored and the LIP reconstruction algorithm showed to be stable for different topology events. Currently, RICH studies are ongoing in the framework of a collaboration with a new PhD student at Geneva University, Manbing Li, under the guidance of Fernando Barão (FB).

Variability studies of cosmic-ray fluxes at low energy and their interpretation under Solar modulation models

Miguel Orcinha (MO) concluded his analysis on the proton flux and submitted his PhD thesis at Instituto Superior Técnico, which will be defended in early 2023. The final effort to estimate the proton flux included the assessment of various systematic uncertainties. In particular, time variability of detector performance, time and rigidity regularisation of efficiencies, the variability of the geomagnetic cutoff, and the unfolding procedure were studied.

Furthermore, a time-series and wavelet transform software framework was developed to characterise CR fluxes in time and frequency. The group determined the temporal periodicities present in the AMS proton daily flux. These periodicities display a complex temporal profile, vary for different rigidities and are highly correlated with solar modulation.

In the framework of the LIP Summer Student programme, the group tutored a student who contributed to the wavelet analysis topic and presented results on the time-series of solar observatories and the space measurements made by the ACE satellite. The student is now part of the group.

The group began work on a solar modulation predictive model for CRs by implementing a stochastic approach to parameter fitting - simulated annealing. This performs random walks through the parameter space while slowly reducing the ´thermal energy´ of the system to avoid getting trapped in local minima. This method is particularly performant for time-series with high variability.

Light isotope nuclei identification

In strong collaboration with the Groningen AMS group, in the scope of Eduardo Bueno's PhD thesis, the LIP group estimated the AMS deuteron flux through an extensive analysis of the singly-charged positive particle flux, which includes a vast majority of protons and a tiny fraction of deuterons and tritiums. The different elements' identification was performed through a mass-template fitting technique. This process came with many challenges and resulted in the development of a mass parametric model to achieve this result.

The group then accurately separated the particles and obtained the three deuteron fluxes corresponding to the ToF and RICH detectors, the latter for both radiators. While this approach extends the flux range as far as detector resolution allows, it requires the three measurements to be individually studied for their resolution and contribution to the smearing of the corresponding fluxes.
To tackle the complex instrumental migrations present in the flux, the group developed a bayesian unfolding method which unfolded and regularised all three particle fluxes simultaneously through a set of iterative steps.

These works resulted in the publication of two papers.

In the framework of the LIP Summer Student programme, the group tutored a student on isotopic separation exploring an alternative data-driven method for estimating mass templates. In this method, the mass templates are iterated from data distributions using a set of linear transformations for the different isotopes. In contrast to traditional mass-template methods, which require the simulation of the detector response in Monte-Carlo.

Lines of work and objectives for next year

Solar activity and modulation of CR fluxes

As the solar activity cycle unfolds, the number of sunspots increases with the number of magnetic domains near the surface of the Sun, perturbing the geometry of its magnetic field. With this increase in activity, more solar events occur, leading to temporary fluctuations in the already complex solar magnetic field that permeates the solar system. This causes a decrease in the total flux of CRs arriving at Earth, a phenomenon known as Forbush decrease.

Alongside with the complex macro-structures created by the heliospheric magnetic field, which envelop the entire solar system, these plays a major role in the propagation of CRs in the solar system. These time-dependent processes constitute what is known as solar modulation and they translates into the CR flux as a low-energy time variability.

Since its launch, AMS has monitored the CR flux with great detail for more than one total solar activity cycle. This level of detailed observation is unprecedented, especially when combined with AMS's statistics and particle separation capabilities.

The typical time scales of the solar activity cycle (daily, 27 days, 11 year activity cycle, 22 year magnetic reversal cycle) can all be observed in AMS data and are one of the current focuses of the collaboration. The group developed a wavelet analysis tool in order to study these time-series and their complex frequency spectra as a function of time and rigidity. Utilizing solar variables as proxies of solar activity and space environment, these time-series will be interpreted under solar modulation models.

The AMS/LIP group developed algorithms to numerically solve the transport equation of CRs in the solar system in several scenarios and approximations (Force-Field, 1D, stochastic). These studies provide a great foothold for the phenomenological study of solar modulation. Alongside with time-frequency analysis, the group intends to use this framework to further study the connection between the solar activity cycle (and the variation of solar observables) and the variations in the CR fluxes measured both by AMS and neutron monitors at ground level.

This aspect of the work will be developed in collaboration with the INFN Perugia AMS group, thus contributing to the CAESAR Project for the ASI (Italian Space Agency) Space Weather Infrastructure. The study of solar modulation using fluxes of particles with different charges and masses (including isotopes and antiparticles) allows probing different aspects of the transport mechanisms.

Selection of nuclei and isotopes using high precision selection algorithms

Apart from helium, the various isotopic analyses are still open or an ongoing topic in AMS, yet to be published. These analyses requiring particle separation, are challenging and deeply dependent on isotope abundance and the presence of backgrounds from heavier nuclei. They require the development of mass identification techniques and the rejection of biases on velocity and rigidity measurements.

Over 2023, a new PhD student at LIP will start isotopic composition studies in AMS. We will focus on Z=1 (hydrogen), a work started by a previous student of the group, and Z=5 (boron) isotopes. During the first year, the student will be introduced tothe flux analysis framework and the event selection criteria, and wil further develop these.

Medium-term (3-5 years) prospects

AMS observed most of the 24th solar activity cycle, through the reversal of the solar magnetic dipole in 2013, and will continue operating through the next magnetic reversal of the current cycle (25th) which is expected to be during 2023, thus observing this phenomenon with unprecedented detail.The group intends to remain focused on flux variability and the study of solar modulation, increasing its footprint on both interpretation and modelling. The group will extend its studies to include isotope fluxes, which will enable probing different aspects of diffusion such as velocity dependence. This topic will also be pursued on the domains of time-series and wavelet analysis.

As stated before, the group has solid knowledge of the AMS experiment, with emphasis in the RICH detector, which measures the velocity of charged particles with great precision. This detector is central in the analysis of isotopes in AMS and particle identification. With the recent arrival of a new PhD student, João Antunes, the group will consolidate its efforts in this domain by studying Z=1 (hydrogen) and Z=5 isotopes (boron).

The group also intends to explore antimatter in the form of antideuterons, in coming years.

SWOT Analysis

Strengths

Experienced team in experimental, astroparticle and computational physics, with extensive computational and data science skills. Long history of international relationships with research groups. Experience in developing analysis frameworks for collaborating with international teams.

Weaknesses and Threats

The main weaknesses and threats are the relatively small size of the group and the lack of scientific overlap between the topics being researched by the group and other LIP research groups.

Opportunities

AMS remains a unique observatory in space. There is increased interest of the scientific community in dark matter origin and cosmic antimatter. AMS' high exposure time gives access to nucleon and anti-matter due to the sheer amount of data Time-variability of CR fluxes is an emerging topic in the scientific community.

AMS

Publications

2 Articles in international journals (with direct contribution from team)

- *"A parametric approach for the identification of single-charged isotopes with AMS-02"*, E. Bueno, F. Barão, M. Vecchi, NIMA A 1031 (2022) 166564
- *"Iterative-Bayesian unfolding of cosmic-ray isotope fluxes measured by AMS-02"*, E. Bueno, F. Barão, M. Vecchi, NIMA A 1046 (2023) 167695

1 Article(s) in international journals (with indirect contribution from team)

- *"Properties of Daily Helium Fluxes"*, AMS Collaboration, Phys.Rev.Lett. 128 (2022) 23, 231102

2 LIP Students Notes

- *"Unravelling time variability in solar activity"*, Rafael Parente, LIP-STUDENTS-22-16
- *"Application of a Data Driven Method to Isotopes Identification in the AMS"*, Diogo Lemos, LIP-STUDENTS-22-17

Presentations

4 Oral presentations in advanced training events

- Miguel Orcinha: *"Alpha Magnetic Spectrometer - A cosmic-ray observatory in space"*, 2022-03-09, Jornadas da Engenharia Física do Técnico - Inside Views, LIP - Lisboa, Portugal
- Miguel Orcinha: *"Alpha Magnetic Spectrometer - A cosmic-ray observatory in space"*, 2022-05-13, Seventh Lisbon mini-school on Particle and Astroparticle Physics, Oeiras, Portugal
- Miguel Orcinha: *"Time Variability in Cosmic-Rays - Variability as a probe"*, 2022-07-20, LIP Internship Program 2022, Instituto Superior Técnico, Lisboa, Portugal
- Fernando Barão: *"Isotopic analysis methods - Mass templates"*, 2022-07-29, LIP Internship Program 2022, Instituto Superior Técnico, Lisboa, Portugal

2 Student presentations in advanced training events

- Diogo Lemos: *"Identificação de isótopos no fluxo de raios cósmicos usando a construção de templates de massa a partir dos dados"*, 2022-09-08, The 6th edition of the LIP Internship Program, LIP - Lisboa, Portugal
- Rafael Parente: *"Variabilidade temporal do fluxo de raios cósmicos"*, 2022-09-08, The 6th edition of the LIP Internship Program, LIP - Lisboa, Portugal

9 Outreach seminars

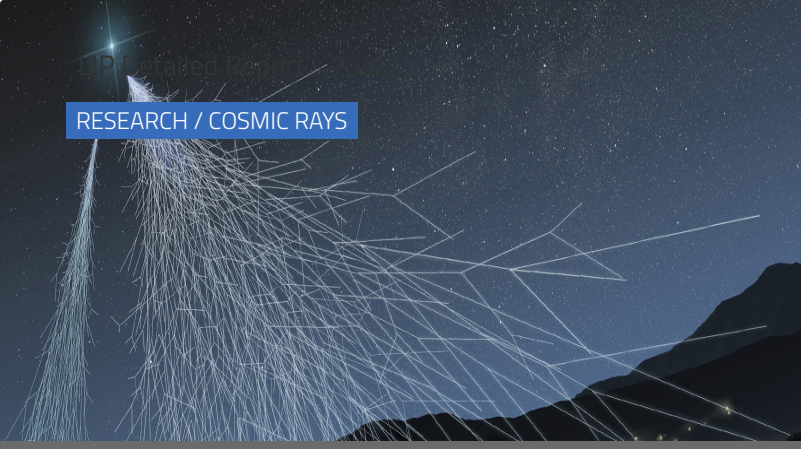
- Luisa Arruda: *"Espaço: Para o infinito e mais além mas em segurança!"*, 2022-10-04, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Secundária António Damásio, Lisboa
- Luísa Arruda: *"Para o Infinito e mais além mas em segurança!"*, 2022-10-19, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Básica Vasco Santana, Ramada, Odivelas
- Luisa Arruda: *"Para o Infinito e mais além mas em Segurança!"*, 2022-10-26, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Básica Elias Garcia, Sobreda, Almada - 7º ano
- Luisa Arruda: *"Para o Infinito e mais Além mas em Segurança!"*, 2022-11-08, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Secundária Marquês de Pombal, Lisboa - 10º ano
- Luisa Arruda: *"Para o Infinito e mais além mas em Segurança!"*, 2022-11-11, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Secundária Dr. António Carvalho Figueiredo, Loures - 7º ano
- Luisa Arruda: *"PARA O INFINITO E MAIS ALÉM MAS EM SEGURANÇA!"*, 2022-11-15, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Básica e Secundária Amélia Rey Colaço, Linda-a-Velha, Oeiras - 8º ano
- Luisa Arruda: *"PARA O INFINITO E MAIS ALÉM MAS EM SEGURANÇA! - LIP"*, 2022-11-25, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Básica Vasco Santana, Ramada, Odivelas - 7º ano
- Luisa Arruda: *"Para o Infinito e Mais além mas em Segurança!"*, 2022-11-29, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Básica Vasco Santana, Ramada, Odivelas - 9º ano
- Luisa Arruda: *"Para o Infinito e mais além mas em Segurança!"*, 2022-12-07, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Secundária Stuart Carvalhais, Massamá, Sintra - 10º ano

Theses

2 PhD

- Eduardo Bueno: *"On the measurement and interpretation of the fluxes of galactic cosmic-ray nuclei"*, 2018-09-06 / 2022-12-06, (finished), Groningen U., Supervisor(s): Fernando Barão
- Miguel Orcinha: *"Estudo da modulação Solar no fluxo de raios cósmicos com dados da experiência AMS"*, 2015-03-30, (ongoing), IST, Supervisor(s): Fernando Barão

RESEARCH / COSMIC RAYS



AUGER

Collaboration in the Pierre Auger Observatory

Principal Investigator:
Ruben Conceição (65)

9 ***Researcher(s):***
Bernardo Tomé (50), Catarina Espírito Santo (15), Liliana Apolinário (15), Mário Pimenta (30), Patrícia Gonçalves (20), Pedro Abreu (60), Pedro Assis (65), Raul Sarmento (70), Sofia Andringa (15)

4 ***Technician(s):***
José Carlos Nogueira (65), Luís Lopes (15), Luís Mendes (75), Miguel Ferreira (65)

4 ***PhD Student(s):***
Alexandra Fernandes (100), Luís Afonso (50), Miguel Martins (50), Pedro Costa (100)

2 ***Master Student(s):***
Beatriz Artur (100), Milton Freitas (100)

2 ***Undergraduated Student(s) and Trainee(s):***
Catarina Felgueiras, Daniel António Sousa

2 ***External collaborator(s):***
Felix Riehn, Lorenzo Cazon

Total FTE:
11.4 (PhD 4.0)

Articles in international journals:	**3** Direct contribution **4** Indirect contribution
Preprint:	**3** Preprints
Notes:	**1** Collaboration note **1** LIP Student note
Datasets, software packages:	**1** Dataset
International conferences:	**4** Oral presentations
Nat.& Internat. meetings:	**4** Oral presentations
Collaboration meetings:	**8** Oral presentations
Advanced Training Events:	**2** Oral presentations **4** Student presentation
Completed theses:	**1** MSc

Executive summary

The Pierre Auger Observatory is the world's largest scientific facility dedicated to studying ultra-high-energy cosmic rays (UHECRs). Running since 2004, it has over the years acquired enough data to change completely the landscape in the field. We know now that the highest energy cosmic rays have an extra-galactic source and are most likely being accelerated in some yet unknown astrophysical source, given the absence of photons and neutrinos. We also learned that there is a cutoff on the energy spectrum, but its origin (UHECRs propagation effect or source exhaustion) is still highly debated. The results of the Pierre Auger collaboration have also provided a complex observational picture. While most of the mass composition-sensitive shower observables display an evolution with energy towards heavier elements, the combined fits to the energy spectrum and the mass-sensitive observables are giving totally unexpected astrophysical scenarios: there should be only a small number of sources around us, all with similar properties and very hard injection spectra. Moreover, the infamous Muon Puzzle - the deficit of muons in simulations when compared with data - is now fully established, despite the hadronic interaction models' efforts to overcome this using the latest available accelerator data. This clearly indicates that our knowledge of extensive air showers is hampered, undermining the UHECR mass composition claims.

The Pierre Auger collaboration is currently entering a new phase – Auger Prime. The observatory is undergoing a massive upgrade to better determine separately the electromagnetic and muonic components of the shower at the ground. For that, scintillation detectors have been installed on top of the working water Cherenkov detectors. The upgrade is expected to be complete in early 2024 and will most likely run until 2030. It is worth noting that this upgrade and the experiment extension time are not aimed for the increase of statistics but to better control the systematic uncertainty of the observatory arising from our knowledge of the shower physics, the reconstruction algorithms and the detectors.

In recent years, the LIP team has been deeply involved mainly in the following tasks: understanding of the shower phenomenology, particularly of muon distributions; development of novel detector concepts to directly measure the shower muonic component; calibration campaigns of the water Cherenkov detectors, using a hodoscope made of resistive plate chambers (RPCs); development of outreach tools.

The pillars of the group's activity listed above are developed in collaboration with the Auger groups in Rio de Janeiro and São Paulo (Brazil) on the development of data acquisition and detector control systems, and in Santiago de Compostela (Spain) on the pursuit of the measurement of EAS muon properties. There is also a strong synergy between the SWGO and Auger LIP groups. This synergy is presently focused on the development of new gamma/hadron discriminators to improve the Pierre Auger Observatory's sensitivity to multimessenger analyses.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Pedro Assis (Ruben Conceição)	FCT	135.000 €	2021-10-01 to 2023-09-30	CERN/FIS-PAR/0012/2021 / AugerEnhance_Upgrade of the measuring capabilities of the Pierre Auger Observatory
Ruben Conceição (Pedro Assis)	FCT	70.000 €	2021-10-01 to 2023-09-30	CERN/FIS-PAR/0020/2021 / UHECR@Auger_UHECR Physics with the Pierre Auger Observatory

Auger

Overview

The Portuguese group in Auger is active in the detailed study of extensive air showers, being highly invested in the creation of novel observables to break the degeneracy between primary mass composition and hadronic interaction models and to boost the observatory sensitivity to neutral particles and multimessenger analyses.

The group is also involved in the development and application of new detectors, namely Resistive Plate Chambers able to operate under harsh environmental conditions, to detect muons directly (MARTA). This technology is steadily evolving with encouraging results and the high precision in timing and position has been explored with hodoscopes which have allowed to perform essential calibrations of the WCDs. These efforts will continue in order to further understand the calibration procedures of the scintillators of Auger Prime being installed at the top of WCDs.

Outreach has been, in the past years, an important mark of the group. Novel tools have been developed, and recently, an activity based on the analysis of data from the Pierre Auger Observatory developed at LIP group became part of the International Particle Physics Outreach Group (IPPOG) Masterclass programme.

A group member coordinates one of the main physics collaboration tasks dedicated to the study of Air Shower Physics.

Assessment of the past year: objectives vs. achievements

In the last year, the group had two major activities to be pursued:

- Commission a MARTA station and the RPC hodoscope installed at the Gianni Navarra WCD test tank;
- Pursue EAS characterization studies and assess the current and future detector capabilities.

MARTA, consisting of a layer of RPC detectors placed underneath the water-Cherenkov detectors, is an R&D project which intends to measure the shower muon component directly. During 2022, there was a campaign that allowed to solve all the previously encountered difficulties in installing the MARTA unit, and the WCD-RPC station "Peter Mazur" is now fully equipped and ready to start taking data. In order to guarantee a stable working efficiency in these feasibility tests, the four RPC were placed in two layers to ensure overlap. In the MARTA concept, four RPCs are placed in a single layer below the tank.

In parallel, the RPC hodoscope installed in the Gianni Navarra tank was reconfigured to include one of the Auger Prime detectors (the scintillator on top of the tank). The data acquisition system was also upgraded to cope with the new electronics board of the WCD and have a more robust/faster acquisition system.

Regarding shower physics, after the great success with the publication on the relative fluctuations in the number of muons, the group focused on two structural tasks: understand the universality level of the EAS muon distributions; investigate the ability of hadronic models with effective implementations of the quark-gluon plasma to describe the Auger data, in particular the "muon puzzle".

The former of these tasks resulted in a work about to be published in a high impact factor journal (JCAP). One of the main conclusions is that EAS muon distributions are essentially universal, except for the energy spectrum. This puts pressure on the extremely difficult measurement of the energy of shower secondary muons and could be used to validate/refute certain hadronic interaction models.

The study on quark gloun plasma and cosmic rays was conducted in collaboration with members of LIP's phenomenology group, resulting in a Master thesis. It is shown that this new class of models has the potential to solve the muon puzzle. This is achieved essentially by increasing strangeness and baryon production combined with the increase of the primary mass composition with energy. While these models can successfully explain the shower features observed by the Auger collaboration, this is done at the cost of a higher number of parameters, which have not been verified by accelerator experiments.

Additionally, members from the group were actively participating in several Auger editorial boards given their expertise in different topics, namely: limits on the Lorentz invariance violation using EAS muon data; measurement of the number of muons using radio and WCD hybrid events; testing model predictions on the depth of air-shower maximum and signals in surface detectors using hybrid data; and the publication of the top-100 Auger high energy events.

The group has been highly invested in the development of outreach ativities on Auger and astroparticle physics to high-school and undergraduate students. The 3D Auger visualizer developed a few years ago has been upgraded to include inclined showers and showers recorded with the elevated fluorescence telescopes. The visualizer is accessible on the Pierre Auger collaboration web site and became the standard visualization tool for the Auger open data.

Members of the group have been working in the past years on a masterclass using Auger data and the LIP event viewer. During 2022, this masterclass was tested internationally for the first time, in collaboration by LIP and INFN - Naples, Lecce and L'Aquila. At the end of the year, the masterclass was approved by the Auger collaboration and integrated in the official IPPOG international masterclasses on particle physics. Also last year, the virtual reality software developed at LIP was turned into an autonomous system (installed in a new set of virtual reality goggles)- Furthermore, besides the use of the Auger shower visualizer, it is now possible to see (and even to enter) a virtual model of an Auger water Cherenkov detector with all its components.

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Lines of work and objectives for next year

For the next year, the activities of the group will be centred around four main pillars: MARTA/Calibration activities; EAS phenomenology; Searches for Neutral Particles; Outreach activities.

Task 1 - MARTA/Calibration activities

The activities proposed in this task take advantage of the RPC hodoscope installed at the test tank near the central campus, in Malargue, and of the MARTA station in the field. Some will be conducted in collaboration with Auger groups in Brazil.

- Operate the RPC hodoscope to obtain atmospheric muons data, which will allow us to better understand the inter-calibration of the WCD and the newly installed scintillator detectors (SSD);
- Use the RPC hodoscope data to develop calibration strategies in the field, including the calibration of the SSD;
- Investigate the possibility of measuring the WCD/SSD response to atmospheric muons with highly inclined trajectories;
- Start acquiring shower data at the Peter Mazur SD station (MARTA unit), which is part of the 750 m array. Validate operation using showers;
- Use acquired data to understand the operation and efficiency stability of the RPCs in the field;
- Investigate the possibility of using shower data to calibrate or assess the health of the WCD + SSD + RPC detectors;

Task 2 - EAS phenomenology

The activities in this task aim to achieve a deeper understanding of the physical mechanisms of shower development and look for the best quantities/strategies to measure its critical parameters. The work will be conducted in collaboration with the Santiago de Compostela Auger group. In particular, a former MSc student in our group is now a PhD student in Santiago, co-supervised by a member of the LIP Auger group.

- Investigate the sensitivity of the footprint on ground of inclined showers to the muon energy spectrum. Up to now the footprint maps, used to extract the EAS muon content, have been treated as being independent from the primary composition. However, the Earth's magnetic field bends muons, which travel large distances before reaching the ground, and the curvature dependents on energy;
- In simulation, investigate the connection between the exponential tail in the number of muons' distribution at ground and the high-energy tail of the pion energy spectrum in the first interaction.

Task 3 - Searches for Neutral Particles

Multi-messenger searches are today one of the main challenges for astroparticle experiments. The activities proposed below aim at enhancing the Observatory's sensitivity to photons and photon-emitting astrophysical sources. Synergies with the LIP SWGO group shall be further explored.

- Investigate the muon distributions close to the shower core and assess the possibility of using this information two discriminate between gamma and hadron-induced showers;
- Explore some of the novel shower observables designed for SWGO to discriminate between gamma/hadron, namely LCm, a quantity that measures the shower azimuthal asymmetry. Preliminary tests done using shower simulations show a high potential of this quantity to identify photon-induced showers at Auger energies, but the quantity has to be completely re-designed to be measurable by the Observatory. It should be pointed out that LCm can be assessed by any ground array sensitive to the shower calorimetric information;
- Define the physics requirements to detect the very high-energy electromagnetic counterpart of Fast Radio Bursts (FRB). Assess the observatory's capabilities to conduct such a measurement (or to set limits) with the present and upgraded Auger photon sensitivity.

Task 4 - Outreach activities

- As stated the Auger masterclass developed at LIP is now established as part of IPPOG's official Hands-on Particle Physics masterclasses. In the 2023 edition, the Auger masterclass is scheduled for two dates, and several national and international participating institutes will join.
- Further developments on the Auger 3D visualizer are expected, adding more information about the showers and the new detectors, e.g.: SSD, muon detectors (UMD), radio. The objective is to create a tool that the collaboration can use to explore the full Auger data;
- The virtual reality goggles will be updated to include the upgrade detectors, namely SSD, an important step for outreach of Auger Prime;
- The virtual reality goggles will be used in the Visitor Center in Malargue;
- Seminars and outreach events will continue to be organized by the group.

This activity plan is well-aligned with the collaboration's main drivers. It is expected to boost activities around the Auger upgrade and aims at enhancing the observatory's sensitivity to the properties of hadronic interactionand to multi-messenger events.

Medium-term (3-5 years) prospects

Understanding the nature of cosmic rays and the interactions of particles at the highest energies is paramount to further advance knowledge in this field. The Pierre Auger Observatory is the reference facility to perform such studies. LIP is well integrated in the collaboration, with clear and strong responsibilities in detectors, analyses and phenomenology studies. LIP group members have responsibilities in task coordination and have served in committees and management bodies of the collaboration.

The next years are going to be challenging. The Observatory enters a new phase, with detector upgrades aimed at better understanding the physical mechanisms of shower development and controlling the multiple systematic uncertainties related to detectors and shower reconstruction. Machine learning algorithms are revolutionizing the collaboration activities, delivering an unprecedented amount of data, which was thought impossible to reach before. The increase in statistics is revealing many hidden features in data and presenting perplexing scenarios. However, they also question the control of of systematics in the different scenarios.

Hence, the coming years shall be dedicated to the strict scrutiny of the shower components and the assessment of systematic uncertainties taking advantage of the detector upgrades and multiple R&D facilities, particularly the ones operating at shower energies equivalent to the ones obtained at the Large Hadron Collider.

The LIP-Auger group has a long expertise in air shower phenomenology, shower and detector simulations, and detector calibrations using RPC-based hodoscopes. Moreover, the group members are known for proposing innovative observables and measurements and novel detector concepts. As such, the group has the necessary expertise to continue to have a large impact in the collaboration. And the upgraded Pierre Auger Observatory will certainly have a great impact in the field of Astroparticle Physics in the coming years.

SWOT Analysis

Strengths

The LIP team is relatively large, both in the number of members and competences.

FCT has a long-term commitment to the Portuguese participation in the Pierre Auger Observatory, which hopefully can be extended up to 2030. This assures the payment of the contribution foreseen in the MoU.

Weakness

The team has a small number of MSc and PhD students, leading to a lack of workforce, particularly in task 2 (EAS phenomenology).

The group's funding level is low for the number of team members. Resources are limited, thus, missions for meetings and fieldwork in Argentina must be wisely chosen.

Opportunities

The group has a strong competence in extensive air shower phenomenology, simulation, and calibrations using RPC hodoscopes. This places the group in a privileged position for the required collaboration activities upon entering the new phase.

Visibility within the universities is increasing, which is an opportunity to attract new students. Lecturing in the Master in Physics program at IST and participating in thematic schools is increasing the awareness of this field.

Threats

The funding of the group has been renewed every two years through the Fund CERN application. The current funding assures the group's operation until the end of 2023.

Auger

Publications

3 Articles in international journals (with direct contribution from team)

- *"A Catalog of the Highest-Energy Cosmic Rays recorded during Phase I of Operation of the Pierre Auger Observatory"*, The Pierre Auger Collaboration, Astrophysical Journal Supplement
- *"The Muon Puzzle in cosmic-ray induced air showers and its connection to the Large Hadron Collider"*, Johannes Albrecht, Lorenzo Cazon, Hans Dembinski, Anatoli Fedynitch, Karl-Heinz Kampert, Tanguy Pierog, Wolfgang Rhode, Dennis Soldin, Bernhard Spaan, Ralf Ulrich, Michael Unger, Astrophys. Space Sci. 367 (2022) 27
- *"Arrival Directions of Cosmic Rays above 32 EeV from Phase One of the Pierre Auger Observatory"*, Pierre Auger Collaboration, Astrophys. J. 935 (2022) 170

4 Articles in international journals (with indirect contribution from team)

- *"Testing effects of Lorentz invariance violation in the propagation of astroparticles with the Pierre Auger Observatory"*, Pierre Auger Collaboration / Pierre Auger Collaboration, J. Cosmol. Astropart. Phys. 1 (2022) 023
- *"A Search for Photons with Energies Above 2 x 10(17) eV Using Hybrid Data from the Low-Energy Extensions of the Pierre Auger Observatory"*, Pierre Auger Collaboration, Astrophys. J. 933 (2022) 125
- *"Search for Spatial Correlations of Neutrinos with Ultra-high-energy Cosmic Rays"*, IceCube Collaboration / IceCube Collaboration / Pierre Auger Collaboration / Telescope Array Collaboration, Astrophys. J. 934 (2022) 164
- *"Searches for Ultra-High-Energy Photons at the Pierre Auger Observatory"*, Pierre Auger Collaboration, Universe 8 (2022) 579

1 Collaboration note(s) with internal referee

- *"Search for point-sources of neutrals through the analysis of spacetime autocorrelations "*, Miguel Alexandre Martins, Lorenzo Cazon, Ruben Conceição, Enrique Zas, Jaime Alvarez-Muñiz, GAP2022_046

1 LIP Students Note(s)

- *"Muography of a water-Cherenkov detector of the Pierre Auger Observatory"*, Catarina Felgueiras, Daniel António Sousa, LIP-STUDENTS-22-15

1 Dataset

- *"Pierre Auger Observatory Open Data (2.0) [Data set]. Zenodo. "*, The Pierre Auger Collaboration, Zenodo

Presentations

4 Oral presentations in international conferences

- R. Conceição on behalf of the Pierre Auger Collaboration: *" Muon measurements with the Pierre Auger Observatory"*, 2022-05-24, 21st ISVHECRI, India (Virtual conference)
- Felix Riehn, Ralph Engel, A. Fedynitch, T.K. Gaisser and T. Stanev: *"UHE hadronic interactions in air showers, Sibyll and the muon puzzle"*, 2022-05-24, 21st International Symposium on Very High Energy Cosmic Ray Interactions - ISVHECRI 2022 , Online
- Raul Sarmento for the Pierre Auger Collaboration: *"Development of an International Masterclass with the public data of the Pierre Auger Observatory"*, 2022-09-16, CRIS 2022 - 12th Cosmic Ray International Seminar, Naples, Italy
- Felix Riehn, Anatoli Fedynitch, and Ralph Engel: *"Muon enhancement ad extremum in Sibyll"*, 2022-10-05, UHECR 2022 - 6th International Symposium on Ultra High Energy Cosmic Rays, Gran Sasso Science Institute, L'Aquila, Italy

4 Oral presentations in national or international meetings

- Mário Pimenta: *" Jorge Dias de Deus (1941-2021) : Science in the Republic"*, 2022-07-04, Third Joint Workshop IGFAE / LIP, Santiago de Compostela, Spain
- Pedro Assis: *"The MARTA project in AugerPrime : RPCs to detect muons in the Pampa"*, 2022-07-04, Third Joint Workshop IGFAE / LIP, Santiago de Compostela, Spain
- F. Riehn: *"Status of hadronic interaction models in C8"*, 2022-07-13, CORSIKA 8 Air-Shower Simulation and Development Workshop, Heidelberg, Germany
- F. Riehn: *"SIBYLL"*, 2022-07-14, CORSIKA 8 Air-Shower Simulation and Development Workshop, Heidelberg, Germany

2 Oral presentations in advanced training events

- Raul Sarmento: *"Astroparticle Physics"*, 2022-07-12, LIP Summer Internships 2022, LIP, Portugal
- Mário Pimenta: *"Observing and modelling the Universe: from the XIX to the XXI century"*, 2022-08-29, 11th IDPASC school , Olomouc, Czech Republic

4 Student presentation(s) in advanced training event(s)

- Daniel Sousa: *"Muography of a water-Cherenkov detector of the Pierre Auger Observatory"*, 2022-09-08, LIP Internship Program 2022, Braga, Portugal
- Alexandra Fernandes, Supervisor Raul Sarmento, Co-supervisors Ruben Conceição, Nuno Castro: *" Enhanced Searches with the Pierre Auger Observatory in the Era of Multi-messenger Astrophysics"*, 2022-07-06, 7th LIP/IDPASC student workshop, Coimbra
- Raul Sarmento: *"Astroparticle Physics"*, 2022-07-12, LIP Internship Program 2022, LIP, Portugal
- Alexandra Fernandes, Raul Sarmento (Supervisor), Ruben Conceição (co-supervisor), Nuno Castro (co-supervisor): *"Enhanced Searches with the Pierre Auger Observatory in the Era of Multi-messenger Astrophysics"*, 2022-08-29, 11th IDPASC School, Olomouc, Czech Republic

Theses

4 PhD

- Luís Afonso: *"Raios Cósmicos: desenvolvimento de módulos de divulgação através design participativo"*, 2021-11-23, (ongoing), UP, Supervisor(s): Pedro Assis,
- Miguel Martins: *"Study of hadronic interactions through the muon component of inclined extensive air showers with the Pierre Auger "*, 2022-01-01, (ongoing), IGFAE/USC, Supervisor(s): Lorenzo Cazon, Ruben Conceição
- Alexandra Fernandes: *"Enhanced Searches with the Pierre Auger Observatory in the Era of Multi-messenger Astrophysics"*, 2022-01-01, (ongoing), UMinho, Supervisor(s): Raul Sarmento, Ruben Conceição, Nuno Castro
- Pedro Costa: *"Multi-messenger physics with the Pierre Auger Observatory and SWGO"*, 2022-02-11, (ongoing), IST, Supervisor(s): Ruben Conceição, Mário Pimenta

2 Master

- Beatriz Artur: *"Impact of Quark-Gluon Plasma in Extensive Air Showers"*, 2021-10-01 / 2022-12-02, (finished), IST, Supervisor(s): Ruben Conceição, Liliana Apolinário
- Milton Freitas: *"Measurement of the number of muons in high occupancy MARTA stations"*, 2021-10-06, (ongoing), IST, Supervisor(s): Ruben Conceição, Pedro Assis

SWGO

R&D for the Southern Wide-Field Gamma-ray Observatory (SWGO)

Principal Investigator:
Mário Pimenta (50)

9 ***Researcher(s):***
Alessandro de Angelis (30), Bernardo Tomé (40), Catarina Espírito Santo (30), Fernando Barão (15), Giovanni La Mura (100), Paulo Fonte (15), Pedro Abreu (40), Pedro Assis (20), Ruben Conceição (35)

4 ***Technician(s):***
José Carlos Nogueira (20), Luís Lopes (15), Luís Mendes (40), Miguel Ferreira (20)

3 ***PhD Student(s):***
Borja González (100), Lucio Gibilisco (100), Pedro Costa (50)

5 ***Undergraduated Student(s) and Trainee(s):***
Afonso Guerreiro, Aroa Diz Penas, Gonçalo Trindade, José Bernardo Ferreira, Miguel Godinho

3 ***External collaborator(s):***
Adriano Henriques, Alberto Guillén, Pedro Brogueira

Total FTE:
7.2 (3.8)

Articles in international journals:	**6** Direct contribution
Preprint:	**2** Preprints
Notes:	**3** Internal notes **2** LIP Students notes
International conferences:	**3** Oral presentations
Nat.& Internat. meetings:	**3** Oral presentations **4** Posters
Collaboration meetings:	**10** Oral presentations
Advanced Training Events:	**2** Oral presentations **4** Student presentations
Seminars:	**4** Seminars

Executive summary

This project aims to ensure the Portuguese participation in the design and prototyping of a ground array able to monitor the Southern gamma-ray sky covering an extended energy range from the low energies, closing the gap between satellite and ground-based measurements, to very high energy regions, beyond the PeV scale. The observations of gamma-ray telescopes over the last decades changed our perception of the Universe radically. At low energies, high-intensity flares with an energy spectrum extending beyond the GeV have been observed. At the highest energies, the recent identification in the Northern sky of more than 12 sources of gamma rays with energies up to the PeV opens definitively a new Era.

In May 2019, in a meeting hold in Lisbon, a new international collaboration was formed, the Southern Wide-Field Gamma-ray Observatory (SWGO), which joins now 80 research institutions from 14 countries and scientists from 10 additional countries, supporting SWGO at an individual level.

SWGO's extended energy range would provide a rich science program, from the observation of multi-messenger and transient events to the probing of the high-energy Universe and fundamental physics. Moreover, all present large field-of-view (FoV) gamma-ray observatories are in the Northern hemisphere. Thus, SWGO will be the only wide-field gamma-ray observatory that will survey the Southern sky, being also able to issue pointing alerts to imaging atmospheric Cherenkov telescopes (IACTs), namely to the future Cherenkov Telescope Array (CTA).

The collaboration has an ambitious plan to produce a complete proposal by the end of 2024, including the physics goal, location, observatory layout, and detector unit design, and cost.

The Portuguese participation in SWGO covers several different areas: definition of the science requirements, detector design, development of new analysis methods, education and outreach activities. In 2022, the priorities were:

- Detailed design and performance studies of the “Mercedes station”, a single-layered small Water Cherenkov detector (WCD), which is a candidate to become the adopted SWGO detector unit;
- Development of gamma/hadron discriminators, both for the lower energy region (100 GeV- 10 TeV), based on machine learning algorithms, and for the higher energy region (10 TeV – few PeV), based on a new variable, LCm, which quantifies the azimuthal fluctuations of the particle distributions at the ground.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Mário Pimenta (Ruben Conceição)	FCT	249.585 €	2021-05-15 to 2024-05-14	PTDC/FIS-PAR/4300/2020 / SWGO: the wide-field gamma-ray observatory at the Southern hemisphere

SWGO

Overview

The main goal of the SWGO (Southern Wide-field Gamma-ray Observatory) collaboration is to pave the wat towards the next-generation wide field-of-view gamma-ray observatory to be installed in South America. The collaboration comprises 80 research institutions from 14 countries. The LIP SWGO group ensures the participation of Portugal in this ambitious project.

SWGO's top decision body is the Steering Committee, with representatives from each participating country. The work is organised into five Working Groups (WG): Site; Science; Simulations and Analysis; Detectors; Communication and Outreach. LIP is actively participating in all the WGs. M. Pimenta is the Portuguese representative on the steering committee; R. Conceição is one of the coordinators of Simulations and Analysis; L. Mendes is responsible for the logistics evaluation subtask for the site working group.

Assessment of the past year: objectives vs. achievements

Task 1 - Detector R&D and site

In 2021, the LIP group proposed the novel detector unit concept of a small single-layer water Cherenkov detector with three photomultiplier tubes (PMT) placed at its bottom, in a 120º star configuration - the Mercedes WCD. In 2022, this concept was extended and translated into a proposal which complies with stringent requirements:

- Be easy to install, deploy and maintain at a reasonably low cost, in large areas, with variable fill factors (FF);
- Work smoothly for long periods (several years) exposed to wide temperature excursions and severe wheather conditions;
- Be sensitive to low energy EAS electrons and photons and able to tag efficiently vertical or inclined muons, even in the presence of a sizeable amount of electromagnetic signal in the detector;
- Have a good timing accuracy (at the nanosecond level).

A test set-up for full-size prototypes was installed at the CBPF premises in Rio de Janeiro and is now fully operational. A detailed station thermal simulation model using a professional code (ANSYS Fluent) was finalized and optimized to maintain its high accuracy while substantially reducing the needed computing time.

A member of LIP who has considerable experience in installing and testing equipment at the Auger Observatory site participated in the two weeks visit to the proposed sites in Argentina, Chile and Peru.

Task 2 - Simulation and analysis

In 2022 the LIP group proposed a new gamma/hadron discriminant variable (LCm) based on the signals collected in the detector stations. This variable quantifies the azimuthal non-uniformity in the pattern of the shower at the ground. Within the limited statistics then available, it was shown that, in the energy range 10 TeV-1 PeV, LCm had a discrimination power similar to the one of a variable based on the number of muons detected at the ground.

At lower energies, Machine Learning (ML) techniques based on muon identification in each Mercedes station (using the PMT signal time structure) give S/√B values well above 4 for S between 0.4 and 0.9, where S and B are the selection efficiency for gammas and protons, respectively.

The commitment of the LIP group to the development of the SWGO simulation framework and reconstruction tools was vigorously pursued. The Mercedes station is now fully implemented in the SWGO framework as well as both the LCm and the ML algorithms.

Task 3 – Phenomenology

New analysis paths were explored. We highlight the work on:

- Study of the relationships between the emission of γ rays and the optical spectra of a sample of AGN, selected from BL Lac sources detected by the Fermi Large Area Telescope (Fermi-LAT);
- Evaluation of the potential of a gamma-ray observatory to detect astrophysical neutrinos through inclined showers.

Both works led to peer-reviewed publications.

Task 4 – Outreach

A tool to visualize SWGO simulation events produced with the SWGO common software framework has been developed, primarily for outreach and education purposes. It is now available for the collaboration as an analysis tool to help understand the characteristics of extreme events.

Lines of work and objectives for next year

The decision of the collaboration on the site and detector design should be taken by mid-2024 and then endorsed by the funding agencies. It will be an iterative process, combining the demonstration on simulation of the capability of the proposed solutions (for the detector unit and for the observatory layout) to comply with the physics program with the readiness and maturity of the proposed technologies. Other important aspects are cost estimation (deployment, installation, maintenance and disassembly and the support of the local authorities.

LIP's proposal of a variable fill-factor array of Mercedes stations (small, single-layered WCD) equipped with different numbers of PMTs, combined with the use of new gamma/h discriminators is well established. In 2023 we must obtain its figures of merit within the SWGO general simulation and reconstruction framework and start producing realistic engineering prototypes.

Task 1 - Detector R&D and site

- Prepare an internal SWGO note describing end-to-end our consolidated detector unit proposal, including a description of the materials, production process, deployment and installation procedures, maintenance plan, each with associated costs;
- Produce realistic prototypes for the study of critical issues (e.g. liners) in collaboration with Brasilian companies, and use the rotomolded prototype tank installed at CBPF to test light collection performances;
- Prepare an internal SWGO on the thermal simulation model and check it with field measurements;
- Contribute to the elaboration of a final site characteristics matrix.

Task 2 - Simulation and analysis

- Obtain the figures of merit of our proposed solution for the specific configurations decided by the collaboration, using the SWGO general simulation and reconstruction framework;
- Pursue the contribution to the development of the general SWGO simulation and analysis frameworks, including the production of the Instrument Response Functions (IRFs) for the tested configurations.

Task 3 – Phenomenology

Write and submit to peer-reviewed international journals articles on:

- Counting the number of muons at the ground in proton EAS with energies from the TeV to a few PeV using shallow WCDs;
- Determination of the azimuthal fluctuations and number of muons at the ground in muon-depleted proton air showers at PeV energies;
- Identification of neutral and charged cosmic ray events with energies below a few hundred GeV in wide field observatories;
- Measurement of astrophysical neutrinos with a shower array observatory.

Task 4 – Outreach

- Maintain the SWGO visualizer developed by the LIP group;
- Participate in outreach activities in Portugal, dedicated to the school community and to other publics.

Medium-term (3-5 years) prospects

The main goal of the SWGO collaboration is to pave the way towards the construction of the next wide field-of-view gamma-ray observatory to be installed in South America.

The collaboration aims to produce by the end of 2024 a complete proposal including the physics goasl, site location, observatory layout, detector design, and cost.

In the following two/three years, in parallel with the endorsement by the funding agencies, a first engineering array should be deployed and operated in the selected site.

LIP is actively engaged in:

- Proposing detailed designs for the single detector units and for the observatory layout that allow to explore a wide energy range (100 GeV to tens of PeV) at a reasonable cost;
- Developing innovative analysis methods and publishing the corresponding results in peer-reviewed international journals.

Until mid-2024, our activities are financially supported by a three-year FCT/PTDC project. A funding request for the following three years must then be prepared.

From 2025 on, LIP's priorities will depend on the chosen detector technologies. In any scenario, LIP is fully committed to be part of the future SWGO Observatory, with a leading role in specific areas.

The cooperation with the Brazilian groups, namely with CBPF, will be pursued, exploring also bilateral funding opportunities.

SWOT Analysis

Strengths

Expertise and long experience in cosmic ray research, detector R&D, data analysis, simulations, air shower physics and phenomenology. Close links with Brazilian, Czech, Italian and Spanish groups.

Weakness

The group has been steadily growing but does not yet have the dimension to fulfill the goals of increasing its contribution to the general reconstruction tasks; develop more phenomenological work.

Opportunities

Extended energy range (100 GeV to 10s PeV). Rich science program including multi-messenger, Pevatron and fundamental physics. The only wide-field gamma-ray observatory surveying the Southern sky. Opportunities for different domains of physics and engineering in different phases of the project, from design to construction, operations and data analysis.

Threats

For the moment, funding is guaranteed until mid-2024 only. SWGO is an ambitious project that will imply, in the medium and long term, considerable financial and human resources.

SWGO

Publications

6 Articles in international journals (with direct contribution from team)

- *"Tackling the muon identification in water Cherenkov detectors problem for the future Southern Wide-field Gamma-ray Observatory by means of Machine Learning"*, B.S. González, R. Conceição, M. Pimenta, B. Tomé, A. Guillén, Neural Comput & Applic (2022)
- *"Pyh^alpha A new variable for γ/h discrimination in large gamma-ray ground arrays"*, R. Conceição, B.S. González, M. Pimenta, B. Tomé, Phys.Lett.B 827 (2022) 136969
- *" The relation between optical and γ-ray emission in BL Lac sources"*, G La Mura, J Becerra Gonzalez, G Chiaro, S Ciroi, J Otero-Santos, Monthly Notices of the Royal Astronomical Society, Volume 515, Issue 4, October 2022, Pages 4810–4827
- *"The Mercedes water Cherenkov detector"*, P. Assis, A. Bakalová, U. Barres de Almeida, P. Brogueira, R. Conceição, A. De Angelis, L. Gibilisco, B. S. González, A. Guillén, G. La Mura, L. M. D. Mendes, L. F. Mendes, M. Pimenta, R. C. Shellard, B. Tomé, J. Vícha, Eur.Phys.J.C 82 (2022) 10, 899
- *"Gamma/hadron discrimination at high energies through the azimuthal fluctuations of the particle distributions at ground"*, R. Conceição, L. Gibilisco, M. Pimenta, B. Tomé, JCAP 10 (2022) 086
- *"Evaluation of the potential of a gamma-ray observatory to detect astrophysical neutrinos through inclined showers"*, Jaime Alvarez-Muñiz, Ruben Conceição, Pedro J. Costa, Mário Pimenta, Bernardo Tomé, Phys.Rev.D 106 (2022) 10, 102001

3 Internal Notes

- *"SWGO event visualizer for outreach"*, H. Carvalho, R. Conceição, B. S. Gonzaléz, R. Sarmento, HAP-22-001
- *"Use of Gamma/hadron discrimination LCm type variables in arrays with different fill factors"*, R. Conceição, P. Costa, L. Gibilisco, M. Pimenta, B. Tomé , HAP-2022-004
- *"Gamma/hadron discrimination in arrays of WCDs with different number of PMTs and in arrays of Scintillators"*, R. Conceição, P. Costa, L. Gibilisco, M. Pimenta, B. Tomé, HAP-2022-009

2 LIP Students Notes

- *"Probing the cosmic ray composition with SWGO"*, Afonso Guerreiro, LIP-STUDENTS-22-01
- *"Sky Watching in Gamma Rays: Searching the Universe for High Energy Processes"*, Miguel Godinho, José Bernardo Ferreira, LIP-STUDENTS-22-04

Presentations

3 Oral presentations in international conferences

- Ruben Conceição, Lucio Gibilisco, Mário Pimenta, Bernardo Tomé: *"Gamma/hadron discrimination at high energies through the azimuthal fluctuations of the particle distributions at the ground"*, 2022-07-28, 27th ECRS, 28th July 2022, Nijmegen, Netherlands
- Giovanni La Mura, Ulisses Barres de Almeida,Francesco Longo for the SWGO Collaboration: *"VHE Sky Monitoring with the Southern Wide-field Gamma-ray Observatory"*, 2022-09-07, Roma International Conference on Astroparticle Physics (RICAP 2022), Rome
- Giovanni La Mura, Ulisses Barres de Almeida, Francesco Longo for the SWGO Collaboration: *"VHE Sky Monitoring with the Southern Wide-field Gamma-ray Observatory"*, 2022-09-12, 12th Cosmic Ray International Seminar (CRIS 2022), Naples, Italy

3 Oral presentations in national or international meetings

- R. Conceição on behalf of the LIP-SWGO group: *"The Southern Wide-field Gamma-ray Observatory"*, 2022-07-04, 3rd joint IGFAE/LIP workshop, Santiago de Compostela, Spain
- Mário Pimenta: *" Jorge Dias de Deus (1941-2021) : Science in the Republic"*, 2022-07-04, Third Joint Workshop IGFAE / LIP, Santiago de Compostela, Spain
- Borja S. González, Ruben Conceição, Alberto Guillén, Mário Pimenta, Bernardo Tomé: *"Muon identification and gamma/hadron discrimination using compact single-layered water Cherenkov detectors powered by Machine Learning techniques"*, 2022-09-14, Second MODE Workshop on Differentiable Programming for Experiment Design, Kolymbari, Crete, Greece

4 Poster presentations in national or international meetings

- B.S. González, R. Conceição, A. Guillén, M. Pimenta, B. Tomé: *"Muon identification and gamma/hadron discrimination using compact single-layered water Cherenkov detectors powered by Machine Learning techniques. Second MODE Workshop on Differentiable Programming for Experiment Design"*, 2022-09-14, Second MODE Workshop on Differentiable Programming for Experiment Design, Kolymbari, Crete, Greece
- Pedro Costa: *"Evaluation of the potential of a gamma-ray observatory to detect astrophysical neutrinos."*, 2022-11-14, IST PhD Open Days, Lisboa, Portugal
- Lucio Gibilisco: *"Gamma/hadron discrimination through the azimuthal fluctuations of the particle distributions at ground."*, 2022-11-14, PhD Open Days 2022 - 8th edition, Lisboa, Portugal
- Borja Serrano González: *"Muon identification and gamma/hadron separation using single-layered WCDs at TeV energies"*, 2022-11-16, IST PhD Open Days, IST, Lisboa, Portugal

2 Oral presentations in advanced training events

- Mário Pimenta: *"Observing and modelling the Universe: from the XIX to the XXI century"*, 2022-08-29, 11th IDPASC school , Olomouc, Czech Republic
- Ruben Conceição: *"Searching for the building blocks of our Universe"*, 2022-03-07, Jornadas de Engenharia Física (IST), Lisboa, Portugal

4 Student presentation(s) in advanced training event(s)

- Borja S. González, Ruben Conceição (Supervisor), Alberto Guillén (Co-supervisor), Mário Pimenta (Co-supervisor): *"A next-generation gamma-ray observatory powered by Machine Learning techniques"*, 2022-07-06, 7th IDPASC/LIP PhD Students Workshop, Coimbra, Portugal
- Pedro Costa, Ruben Conceição (Supervisor), Mário Pimenta (co-supervisor): *" Evaluation of the potential of a gamma-ray observatory to detect astrophysical neutrinos"*, 2022-07-06, 7th IDPASC/LIP PhD Students Workshop, Coimbra, Portugal
- Lucio Gibilisco, Ruben Conceição (Supervisor), Mário Pimenta (Co-Supervisor): *"Measurement of PeVatrons with the future Southern Wide-field Gamma-ray Observatory (SWGO)"*, 2022-07-06, 7th IDPASC/LIP PhD Students Workshop, Coimbra, Portugal
- Afonso Guerreiro, supervisors Rúben Conceição and Borja Serrano González: *"Probing the cosmic ray composition with SWGO"*, 2022-09-08, LIP internship program 2022 final workshop, Lisbon

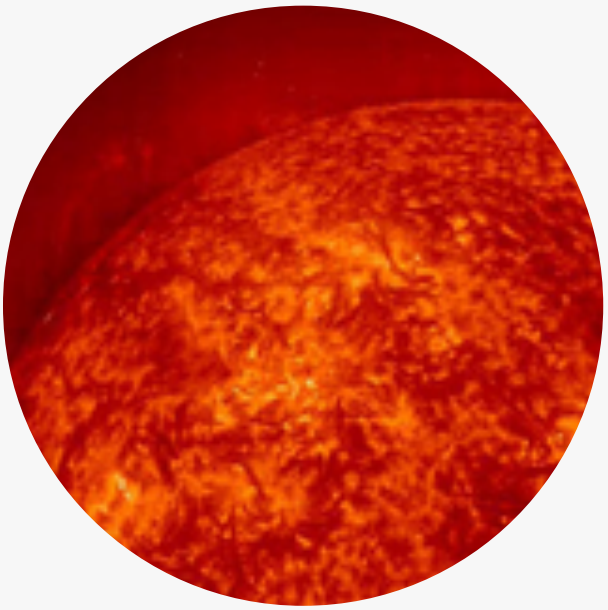
4 Seminars

- M. Pimenta: *"The challenge of detecting Ultra-High-Energy Gamma Rays (> 100 TeV) in the Southern Hemisphere "*, 2022-04-15, Seminar at Padova University, Padova, Italy
- M. Pimenta: *"Ronald Cintra Shellard - 34 anos de trabalhos, projectos e aventuras comuns"*, 2022-05-02, Sessão de homenagem do CBPF para Ronald Shellard, Rio de Janeiro, Brasil (apresentação via Zoom)
- M. Pimenta: *"The challenge of detecting Ultra-High-Energy Gamma Rays (> 100 TeV) in the Southern Hemisphere"*, 2022-05-13, Seminar at IHEP, Beijing, China (zoom)
- Ruben Conceição: *"Astroparticle physics at extreme energies and the muon puzzle"*, 2022-06-15, Café com Física, Coimbra

Theses

3 PhD

- Borja González: *"A next-generation gamma-ray observatory powered by Machine Learning techniques"*, 2020-12-15 / 2025-09-30, (ongoing), IST, Supervisor(s): Ruben Conceição, Alberto Guillén
- Pedro Costa: *"Multi-messenger physics with the Pierre Auger Observatory and SWGO"*, 2022-02-11 , (ongoing), IST, Supervisor(s): Ruben Conceição, Mário Pimenta
- Lucio Gibilisco: *"Reaching for PeVatrons with the future Southern Wide-field Gamma-ray Observatory"*, 2021-09-17 , (ongoing), IST, Supervisor(s): Ruben Conceição, Mário Pimenta



[Dark matter and neutrino]

DarkMatter
Neutrino
SHiP/SND@LHC

DARKMATTER

Participation in dark matter experiments: LUX and LZ

Principal Investigator:
Isabel Lopes (70)

8 ***Researcher(s):***
Alexandre Lindote (100), Cláudio Silva (75), Elias Asamar (8), Francisco Neves (70), Helmut Wolters (20), José Pinto da Cunha (50), Paulo Brás (100), Vladimir Solovov (40)

1 ***PhD Student(s):***
Guilherme Pereira (100)

5 ***Master Student(s):***
Carlos Neto (57), David Carreira (57), Fátima Alcaso (100), Henrique Almeida (46), Sandro Saltão (80)

6 ***Undergraduated Student(s) and Trainee(s):***
Carlos Brito, Cláudia Pereira, Diogo Campizes, Mariana Letra, Paulo Pires, Pedro Caetano de Sá

1 ***External collaborator(s):***
Albert Baker

Total FTE:
9.3 (5.3)

Articles in international journals:	**1** Direct contribution **4** Indirect contribution
Notes:	**13** Internal notes **2** LIP Students notes
International conferences:	**3** Oral presentations **2** Posters
International meetings:	**2** Oral presentations
Collaboration meetings:	**4** Oral presentations
Advanced Training Events:	**1** Oral presentation
Seminars:	**2** Seminars **1** Outreach seminar
Completed theses:	**4** MScs

Executive summary

The LIP Dark Matter group has a long experience in the various aspects of WIMP (Weakly Interating Massive Particles) direct detection experiments, as well as a solid expertise in the physics associated to xenon detectors. Since 2002, the group has participated in several world-leading WIMP direct detection experiments: ZEPLIN II, ZEPLIN III, LUX and LUX-ZEPLIN (LZ) from which LIP is a founding member. Presently, the group is involved in four projects that, although distinct, are closely related: i) LZ experiment; ii) Migdal project; iii) XLZD project; iv) R&D project on optical properties of reflecting surfaces:

i) The data acquired in 2022 corresponds to LZ's first search for WIMPs, with an exposure of 60 live days using a fiducial mass of 5.5 t. A profile-likelihood ratio (PLR) analysis showed the data to be consistent with a background-only hypothesis, setting new limits on spin-independent WIMP-nucleon, spin-dependent WIMP-neutron, and spin-dependent WIMP-proton cross-sections for WIMP masses above 9 GeV/c2. The most stringent limit is set for spin-independent scattering at 30 GeV/c2, excluding cross-sections above 6.5 10-48 cm2 at 90% confidence level, proving LZ as the world's most sensitive WIMP search experiment. After a calibration campaign, the preparation of the second science run (SR2) took place. SR2 started in December 2022.

The group is contributing to several areas of the LZ experiment. We highlight:

- Its leading role in the studies of the LZ sensitivity to the neutrinoless double beta decay (NDBD or $0\nu2\beta$) of ^{136}Xe (the observation of this decay is the second most important physics goal of LZ) and its responsibility on the estimate of the LZ sensitivity to the $2\nu2\beta$ and $0\nu2\beta$ decays of ^{134}Xe, as well as the double electron capture (2EC) of ^{124}Xe.
- Its responsibility for two elements of the experiment infrastructure: the Control System (CS) and the online Underground Performance Monitor (UPM).
- The development of data analysis tools for pulse identification and characterization, as well as position and energy reconstruction, and to the modelling, simulation and accounting of the backgrounds.

ii) In 2020, we have joined a proposal for a UK-based project aiming to observe the Migdal effect, which is theoretically predicted but was never confirmed experimentally. This effect would allow extending the sensitivity of WIMP direct detection double phase xenon TPCs (DPXeTPC) to the sub-GeV mass region (from 4 GeV down to the sub-GeV range). The data dating is about to start.

iii) The XLZD project just started this year, and it is a joint venture of most groups in the LZ, DARWIN and XENON collaborations towards a third-generation (G3) direct detection WIMP search experiment employing a DPXeTPC with about 100 tonnes of xenon. Working groups were formed towards achieving a final design of the detector and planning the experiment.

iv) The R&D project on the study of optical properties of reflecting surfaces is about to be finalized. Measurements were completed in 2022.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Cláudio Silva	FCT	50.000 €	2016-11-01 to 2022-02-28	IF/00877/2015/CP1311/CT0002 / Optical studies for performance and optimisation of the dark matter experiments LZ and LUZ
Isabel Lopes (Francisco Neves)	FCT	249.948 €	2021-06-01 to 2024-05-31	PTDC/FIS-PAR/2831/2020 / Participation in the LUX-ZEPLIN experiment

DarkMatter

Overview

Our main lines of the work in LZ are:

- Physics beyond Dark Matter search with LZ: search for neutrinoless beta decay in ^{136}Xe and ^{134}Xe, as well as other Xe rare decays such as double electron capture in ^{124}Xe and ^{126}Xe, including the use of machine learning algorithms for improving the signal-to-background discrimination.
- Data analysis tools for LZ: encompasses the development of algorithms and techniques for pulse identification and characterization, detector related corrections, position and energy reconstruction and high-level analysis.
- Development of the Underground Performance Monitor system (UPM) for LZ: this is the on-site system that permits to monitor the detector performance and the data quality in real time (we have full responsibility for this system from the very beginning).
- LZ Control system (CS): LIP has full responsibility for the part of the slow control based on Ignition that comprises the control of more than 20000 sensors.

Internal LZ leadership responsibilities:

- LZ Data analysis coordination (PB),
- High Energy Electron Recoil group coordination (AL),
- LZ Control System (VS),
- LZ Underground Performance Monitor (FN).

Internal Migdal leadership responsibilities:

- Analysis framework (FN),
- Data and Run coordination (AL).

The LIP team involved in this project is led by F. Neves.

Internal XLZD leadership responsibilities:

- Co-convener of the neutrinoless double beta decay group (AL),
- Co-convener of the calibrations group (CS).

C. Silva is responsible for the R&D project on optical properties of reflecting surfaces whose funding finished in early 2022.

Assessment of the past year: objectives vs. achievements

I - Participation in LZ

^{136}Xe Neutrinoless double beta decay

- The energy resolution of LZ at high energies was optimised using precise position corrections for both the S1 and the S2 signals (signals in the liquid and gaseous detector volume, respectively). These corrections take advantage of the uniformly distributed alpha decays from the $^{-22}$Rn chain, which are used as "standard candles". We obtained an energy resolution of 0.65% (sigma) near the Q-value of the ^{136}Xe 0vbb decay (2.5 MeV). This is the best energy resolution ever obtained for this energy in a liquid xenon detector.
- The development of algorithms to discriminate multiple scatter events has begun, with the exploration of the temporal profile of the S2 pulses. Preliminary tests using fits with simplified S2 templates on simulated waveforms show that a separation of 3 mm or better is possible even at high depths.

Study of other Xe rare and forbidden decays

Using a 50-day dataset, the half-life of the KK mode of ^{124}Xe 2ν2EC was obtained. The preliminary result was (1.4±0.3±0.2) x10^{22} years.

Position reconstruction and PMT response

A position resolution of 1.35 mm (sigma) was measured for 164 keV electron recoils using the position reconstruction algorithm developed by the LIP group. Also, we proposed several novel techniques aiming to improve spatial uniformity and temporal stability of the detector energy response:

- in-situ determination of PMT linear range and saturation threshold
- in-situ monitoring of PMT gains
- precise position-dependent S1 and S2 corrections obtained by analysing alpha background from ^{222}Rn decays

Backgrounds: modelling and mitigation

The backgrounds database was modified to allow for a more flexible grouping of the normalisation factors obtained from material assays.

LZap

- The LIP group was responsible for the modules for pulse identification and classification. The analysis of the first Science Run (SR1) data required a detailed tuning, especially of the Pulse Finder and Classifier, resulting in a very high detection efficiency even at the low energy range used for WIMP searches.
- The group has also implemented a machine-learning methodology used to inform the development of pulse identification algorithms such as the pulse classifier.
- We are also responsible for the position reconstruction module that gives an important input for event quality cuts as besides the event position it estimates how well an event conforms to the

single scatter hypothesis.

- The development of the photon counting module was continued.

UPM

In 2022 most of the effort on UPM concerned the integration of new tools to monitor the outer detector, namely, its detection efficiency.

Control System

Currently, the Ignition system, comprising nearly 20000 control and telemetry channels, is used as a primary user interface for control and monitoring of the detector and its supporting systems. G.Pereira continues to be the lead Ignition developer. V. Solovov continues as coordinator of the LZ control system.

II - Experimental study of the Migdal Effect

The main achievements in 2022 were:

- Development of an analysis framework for the complete analysis of the Migdal data.
- Development of the MiDAQ (Migdal Data Acquisition System) software, which handles the simultaneous acquisition of waveforms from 66 Acqiris digitizer channels and images from a Hamamatsu Fusion camera, as well as the timing synchronisation between these two data pipelines.

III - R&D on optical measurements of PTFE

Reflectance in a diffuse interface: We have shown that a single parameter, the multiple-scatter albedo ρ, can predict the diffuse reflectance of a material in both air and liquid interfaces. We performed measurements of the reflectance of PTFE in both a liquid (water, glycerol, and cyclohexane) and air interface using a total integrating sphere and for light wavelengths between 250 and 500 nm. A detailed MC simulation was done, and the results were compared with data to estimate ρ. A paper was written and will be submitted for publication soon.

Simulation of the reflectance with a Monte Carlo model: Two main updates were incorporated in the MC simulation of the reflectance. The first was to include the multiple scattering of light due to the roughness of the surface. The second was to replace the Lambertian model by the Chandrasekhar model for isotropic light scattering.

IV – XLZD Project: towards a third-generation dark matter experiment

^{136}Xe $0\boldsymbol{\nu}\beta\beta$ decay: A flexible framework was developed allowing to derive sensitivity estimates for different combinations of the detector parameters. This allowed us to demonstrate that a G3 xenon TPC with 80 tonnes or more of natural abundance xenon and a performance similar to that of the current detectors can compete with experiments exclusively dedicated to this search using enriched xenon. A preliminary study shows that it is possible to identify MS events (a critical parameter for background discrimination) if these are separated by at least 5 mm in the vertical direction, even if they occur at the bottom of a 3 meter high TPC.

Lines of work and objectives for next year

I - Participation in LZ

136Xe Neutrinoless double beta decay

Work will continue on the discrimination of multiple scatter events, testing the developed algorithm with real data and exploring algorithms for discrimination in the horizontal plane. Backgrounds will be studied in detail using real data, including optimization of the skin and OD thresholds and the use of multiple scatter events for improved characterisation. High statistics signal and background simulations will be generated for use in the PLR analysis.

Study of other Xe rare and forbidden decays

We will start focusing on $0\boldsymbol{\nu}2EC$, which is an interesting alternative to $0\boldsymbol{\nu}\beta\beta$ to search for BSM physics. The absence of neutrinos implies that the decay Q-value will be carried by one (or more) high energy gammas in a region (2864 keV) with very low backgrounds, and creating a distinguishing event topology. We will start by generating simulations of the expected signals and backgrounds in this energy region, leading to an estimate of the 90% CL exclusion sensitivity.

Position reconstruction and PMT response

We will try to use S1 response maps to independently reconstruct the point of origin of the S1 signal. This would open the possibility to:

- improve background characterization by reconstructing event positions even for the regions without electric field
- independenly verify maps of electric field and associated S2 position corrections
- create more efficient cuts for the electron recoils with partial charge collection (gamma-x events), a especially dangerous background as they can mimic S2/S1 ratio of nuclear recoils
- create better S1 area correction maps to further improve energy resolution

LZap

- In spite of its proven performance, the Pulse Finder used in LZap and the UPM still presents some limitations, especially concerning its use across a wide span of energy ranges (e.g. WIMP and 0vbb searches). For that matter, the development of a new Pulse Finder algorithm is already underway.
- The pulse classifier algorithms will be updated and tuned to match the evolving detector operation settings. Machine learning methods will continue to be deployed to infer the best way of partitioning and classify signals, thus improving the performance of the existing algorithms.

- We plan to work together with the people responsible for the online databases and PMT monitoring in order to create an information channel that would automatically supply the position reconstruction module with the up-to-date information on the status of the PMTs to guarantee the quality of the produced data.
- The photon counting method will be assessed with different calibration sources. We plan to use this method to estimate the size of both S1 and S2 and measure the improvement in the energy resolution and discrimination between nuclear and electronic recoil. Once this algorithm has been properly implemented and tested, we will use it to study the CEνNS interactions of the Boron-8 solar neutrinos and the subsequent reanalysis of the first science run.

UPM

- Operate and develop the UPM infrastructure and analysis tools to continue responding to the requirements and monitoring needs of the various LZ subsystems;
- It is foreseen to start developing and testing the concept of using ML to detect failure conditions using the UPM data.
- Another possibility under consideration is to start testing the feasibility of using the UPM to in real time multi-messenger signals (e.g. neutrinos and high energy γ-rays) from supernovae bursts.

II - Experimental study of the Migdal Effect

More analysis modules will be added to MiDAS (e.g. ITO and image analysis, 3D track reconstruction) to meet the experiment requirements.

III – XLZD Project: towards a third-generation dark matter experiment

- **^{136}Xe 0νββ decay**: Sensitivity studies will continue (including different detector geometries and ^{136}Xe abundance scenarios), along with more detailed studies of the various backgrounds (in particular the possible vetoing of ^{137}Xe decays). We will also start the implementation of a PLR which includes energy and position information, and extend the statistical analysis to include the 3σ discovery potential. The study of the SS/MS discrimination capability in the vertical direction will continue with more detailed simulations, and exploration of the horizontal plane for additional discrimination will start.
- **Calibrations:** the three major calibrations studies planned for 2023 are the deuterium-deuterium (D-D) calibrations, the tritium calibrations, and the position corrections of the S1 and S2 pulses. The D-D and tritium calibrations are used to calibrate the response of the detector to nuclear and electronic recoils respectively. Finally, we will investigate the best source to calibrate the detector's response with the position.

IV - R&D on optical measurements of PTFE

We plan to write two papers on the Monte Carlo simulation of the reflection and transmittance. The first article is dedicated to reflectance and transmittance in a rough surface, and the second to reflection and transmission from a diffuser. Two major updates are planned to the algorithm described in these two articles: i) to use the Chandrasekhar theory to describe the diffuse reflection in a semi-infinite diffuser and ii) the second is to fully describe diffuse transmission and reflection in a semi-transparent diffuser. Finally, we plan to add these simulations to ANTS-III.

Medium-term (3-5 years) prospects

The group activity will proceed along three directions:

1- LZ is taking data and we will carry out analysis optimization to search for a broad range of rare-event physics searches, including WIMPs, neutrinoless double-beta decay, Xe rare decays, solar neutrinos, and solar axions over an estimated 1000 day exposure. We intend to exploit the data acquired by LZ, in particular for the WIMP and ^{136}Xe 0ν2ß decay searches. We plan to use not only the classical PLR but also to explore machine learning algorithms. We will also be involved in the analysis of the data in search of the other Xe rare decays in which we have been working, i.e., 2ν2β and 0ν2β decays of ^{134}Xe, as well as the 2ν2EC and 0ν2EC of ^{124}Xe.

2 - To strength the participation in the Migdal project with a particular focus on data analysis.

3 - We will be strongly involved in the DLZX project. The most clear opportunity for future intervention in this project is the search for in 0ν2β decay in ^{136}Xe using the dark matter detector to be constructed. The search for this decay will be the second most important physics goal of DLZX. We have a strong expertise and experience on this topic. We intend to contribute and lead the efforts to improve the sensitivity of DLZX detector to this process. We will also explore the possibility of contributing and leading the PMT calibration. However, the project is still in a very initial fase and thus it is not yet clear what will be exactly our responsabilities and involvement in the future DLZX collaboration.

In LZ, the group will continue its commitments regarding the CS and UPM maintenance, as well as the participation in the operation activities. We will also remain responsible for the maintenance and upgrade of the LZ analysis tools that we have developed (i.e., the pulse analysis, position and energy reconstruction modules).

Until May 2024, the group activities are financially supported by a 3-year project FCT/PTDC. A funding request for the next three years must be prepared in the following months.

SWOT Analysis

Strengths

The group has a long experience in the various aspects of WIMP search experiments, as well as a solid expertise in liquid xenon detectors and their physics mechanisms. Due to its wide range of competences and its size, the group can have a participation with relevant impact in LZ and join other international projects related to third generation dark matter experiments. The group has a laboratory in Coimbra to operate liquid xenon detectors.

Weaknesses

The group counts presently with only one PhD student, who will defend his thesis within a couple of months.

Opportunities

LZ is presently the most competitive dark matter experiment in the world, with a high potential of detecting WIMPs. To participate in such an experiment is by itself an opportunity with several components from which we highlight: 1) use and extend our areas of expertise; 2) open the possibility of participating in cutting-edge projects.3) attract students. We have three PhD candidates willing to do their PhD in the group. They are applying to PhD scholarship calls.

Threats

We were funded up to May 2024. However the funding is insufficient to run the project until then. After subtracting a junior researcher contract and the overheads, we have only 26 k€/year for all the expenses. This is not enough to support the human resources required by the project, namely the researchers of the group that finished their contracts with FCT (C. Silva) and/or young researchers that have just completed their PhD and have crucial responsibilities in LZ (G. Pereira). On top of this, the annual international FCT call for contracting researchers in all areas has a very low rate of success (12.5% in Physics in the last call). The funding structure in Portugal continues to be inappropriate to large long term projects. The limited and erratic funding, with frequent time gaps between consecutive calls, are a permanent threat to the project.

DarkMatter

Publications

1 Article(s) in international journals (with direct contribution from team)

- *"A machine learning-based methodology for pulse classification in dual-phase xenon time projection chambers"*, P. Bras, F. Neves, A. Lindote, A. Cottle, R. Cabrita, E. Lopez Asamar, G. Pereira, C. Silva, V. Solovov, M.I. Lopes, Eur. Phys. J. C 82 (2022) 553

4 Articles in international journals (with indirect contribution from team)

- *"The LUX-ZEPLIN (LZ) radioactivity and cleanliness control programs"*, D. S. Akerib et al., Eur. Phys. J. C 82 (2022) 221
- *"Cosmogenic production of Ar-37 in the context of the LUX-ZEPLIN experiment"*, J. Aalbers et al., Phys. Rev. D 105 (2022) 082004
- *"A machine learning-based methodology for pulse classification in dual-phase xenon time projection chambers"*, D. S. Akerib et al. (LUX Collaboration), Phys. Rev. D 106, 072009
- *"Fast and Flexible Analysis of Direct Dark Matter Search Data with Machine Learning""*, D. S. Akerib et al. (LUX Collaboration), Phys. Rev. D 106, 072009

13 Internal Notes

- *"Timing synchronization in the MIGDAL DAQ"*, A. Lindote,
- *"Characterization of the vertical vertex separation of LZ for 136Xe 0νββ decay"*, Sandro Saltão,
- *"0νββ in DMNG"*, A. Lindote and F. Kuger,
- *"Data handling & coordination"*, A. Lindote,
- *"The role of 125I in the 2νECEC 124Xe decay search"*, Henrique Almeida,
- *"A plan for energy resolution field dependency studies in LZ"*, Alexandre Lindote, Cláudio Silva, Paulo Brás et al. , LZ internal report
- *"High-E ER vertical vertex separation in SR1 data"*, P. Brás,
- *"WG1 report for the Summer meeting: Neutrinoless Double Beta Decay"*, Alexandre Lindote, Fabian Kuger, XLZD internal report
- *"S2 pair separation with ML"*, Paulo Brás,
- *"Preliminary results of separation of generated S2 signals"*, Sandro Saltão, LZ internal report
- *"DAQ commissioning update"*, Alexandre Lindote, MIGDAL internal report
- *"Data Acquisition status"*, Alexandre Lindote, MIGDAL internal report
- *"SS/MS discrimination at high energies down to 3m depths"*, Sandro saltão, XLZD internal report

2 LIP Students Notes

- *"Direct detection of dark matter at LUX-ZEPLIN"*, Mariana Sofia Rasteiro Letra, Paulo Pires, Pedro Barata de Tovar Caetano de Sá, LIP-STUDENTS-22-12
- *"Projected sensitivity of the LUX-ZEPLIN experiment to the 0νββ decay of 136Xe"*, Carlos Roxo and Francisco Pais,

Presentations

3 Oral presentations in international conferences

- Guilherme Pereira : *"Energy Resolution of the LZ detector to High Energy Electronic Recoils"*, 2022-05-24, International Workshop on Applications of Noble Gas Xenon to Science and Technology (XeSAT-2022) , Coimbra, Portugal
- Isabel Lopes: *"Searching in the dark:in the hunt for WIMPs"*, 2022-08-25, COSMOS 2022, Rio de Janeiro, Brasil
- Guilherme Pereira (on behalf of LZ): *"Energy Resolution of LZ detector to High Energy Electron Recoils"*, 2022-09-22, LIDINE 2022 Conference (LIght Detection In Noble Elements Conference) , Warsaw, Poland

2 Poster presentations in international conferences

- Paulo Brás (on behalf of LZ Collaboration): *"Neutrino physics with the LUX-ZEPLIN Detector"*, 2022-05-31, Neutrino 2022, Seul,Coreia (virtual)
- A. Lindote and I. Olcina: *"Sensitivity to neutrinoless double beta decay of 136Xe with a third generation TPC dark matter experiment"*, 2022-06-01, Neutrino 2022 , Seoul, Korea (virtual)

2 Presentations in international meetings

- Paulo Brás: *"First Results of the LUX-ZEPLIN Dark Matter Experiment"*, 2022-07-08, Jornadas LIP 2022, Coimbra
- A. Lindote: *"XLZD: Towards a Global Rare Event Observatory"*, 2022-07-08, Jornadas LIP 2022, Coimbra

1 Oral presentation(s) in advanced training event(s)

- Cláudio Silva: *"Research Opportunities in LZ"*, 2022-05-22, 7th Lisbon mini-school on Particle and Astroparticle Physics, Oeiras, Portugal

2 Seminars

- Alexandre Lindote: *"Using two-phase xenon detectors to search for Dark Matter"*, 2022-02-18, , Universidade de Coimbra, Coimbra
- Paulo Brás : *"Rare event searches in the LUX-ZEPLIN dark matter experiment"*, 2022-03-16, , Universidade de Coimbra, Coimbra

1 Outreach seminar(s)

- Paulo Brás: *"À procura da Matéria Desconhecida"*, 2022-10-31, Dark Matter Day Public Seminar, Physics Department University of Coimbra

Theses

1 PhD

- Guilherme Pereira: *"Data processing and Human Machine Interface for the monitoring and control system of LZ dark matter experiment"*, 2018-03-15 , (ongoing), UC, Supervisor(s): Vladimir Solovov, Cláudio Silva

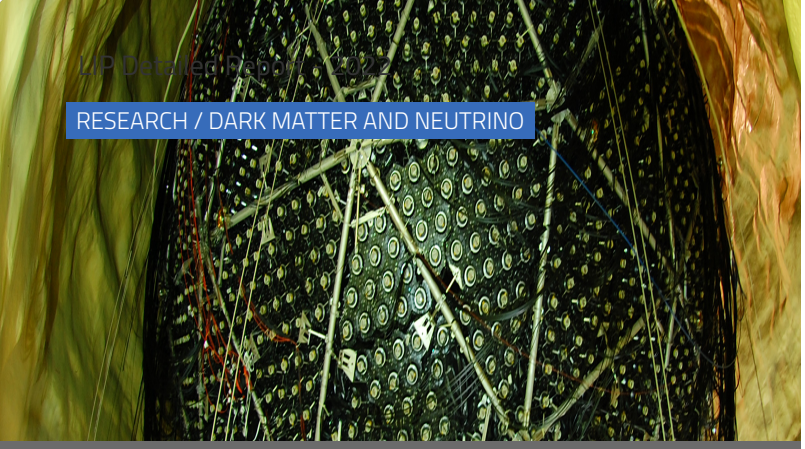
4 Master

- Henrique Almeida: *"Searches for neutrino and neutrino less 2EC decay modes in ^{124}Xe with the LZ detector"*, 2021-09-01 / 2022-09-29, (finished), UC, Supervisor(s): Alexandre Lindote, Cláudio Silva

- Fátima Alcaso: *"Design and optimisation of a xenon TPC with SiPM readout for neutrinoless double beta decay studies"*, 2019-09-15 / 2022-09-30, (finished), UC, Supervisor(s): Alexandre Lindote, Francisco Neves

- Carlos Neto: *"Redes neuronais para deteção de objetos no contexto de navegação natural"*, 2021-09-15 / 2022-09-30, (finished), UC, Supervisor(s): Francisco Neves,

- Sandro Saltão: *"Optimisation of the vertical separation of multiple scatter events in the LZ detector with applications in the sensitivity to the $0\nu2\beta$ decay of ^{136}Xe"*, 2021-09-01 / 2023-02-28, (finished), UC, Supervisor(s): Alexandre Lindote, Paulo Brás



NEUTRINO

Neutrino Physics

Principal Investigator:
José Maneira (100)

8 ***Researcher(s):***
Amélia Maio (30), Cristovão Vilela (*), Fernando Barão (30), Francisco Neves (15), Nuno Barros (100), Sofia Andringa (50), Valentina Lozza (60), Vladimir Solovov (15)

1 ***Technician(s):***
Rui Alves (10)

2 ***PhD Student(s):***
Ana Sofia Inácio (100), Wallison Campanelli (39)

2 ***Master Student(s):***
Joana Vences (28), João Carlos Antunes (100)

4 ***Undergraduated Student(s) and Trainee(s):***
Carlos Roxo, Gil Ramos Madeira, Margarida Ferreira, Nuno Agostinho

1 ***External Collaborator(s):***
Matthew Cox

Total FTE:
6.8 (PhD 4.0)

(*) Starting in December 2022

Articles in international journals:	**3** Direct contribution **3** Indirect contribution
Notes:	**1** LIP Students note
International conference:	**1** Oral presentation
Nat.& Internat. meetings:	**1** Oral presentation
Completed theses:	**1** PhD **1** MSc
Organized Events:	**1** International Conference or Workshop

Executive summary

The LIP Neutrino Physics group currently participates in the SNO+ experiment at SNOLAB and in the Deep Underground Neutrino Experiment (DUNE) at Fermilab, SURF and CERN. There is a strong (but not complete) overlap between the SNO+ and DUNE teams, and we pursue a common strategy of balancing data analysis of a current experiment (SNO+) with the development of hardware and analysis methods for a future one (DUNE).

The group was formed in 2005 to join the Sudbury Neutrino Observatory (SNO) experiment, and soon after was a founding member of a new collaboration – SNO+ – aiming at reusing the SNO detector in the search for the neutrinoless double-beta decay (DBD) of ^{130}Te. The group has been very much involved in the construction of the SNO+ calibration systems and is currently very active in the data analysis of the water and scintillator fill (half-full and full detector) phases, with leadership or strong contributions to physics analyses (backgrounds and antineutrino studies) and calibrations. The filling of the detector with LAB liquid scintillator with nominal PPO fluor levels was completed in April 2022. While the Tellurium purification and loading systems are being commissioned, the detector is now taking high quality data that allows the measurement of antineutrinos from nuclear reactors and the Earth's natural radioactivity, solar and supernova neutrinos, and searches for new physics.

The group joined the DUNE collaboration in 2018, with the goal of participating in one of the leading neutrino physics experiments of the next decades. Due to the three main aspects of its design – wide-band energy, long baseline, excellent detector performance – DUNE will be unique in measuring CP violation and neutrino mass ordering in the same experiment. Leveraging on the needs of the experiment and the experience of the team, we focus our activities on the design and construction of the far detector calibration systems – mechanics and electronics. We lead the Calibration and Cryogenic Instrumentation Consortium (one of eleven consortia). Testing the designs of the calibration systems at ProtoDUNE-II at CERN, as well as analyzing its data, is a priority for the next few years. Due to the recent arrival of a new group member, we plan to also contribute to the Near Detector and the Oscillation physics activities.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Valentina Lozza	FCT	50.000 €	2017-01-01 to 2022-03-31	IF/00248/2015/CP1311/CT0001 / FCT Exploratory project in SNO+ (V. Lozza)
José Maneira (Nuno Barros)	FCT	90.000 €	2021-09-01 to 2023-08-31	CERN/FIS-PAR/0014/2021 / DUNE - Calibration of ProtoDUNE-II at CERN
Nuno Barros (Valentina Lozza)	FCT	231.005 €	2021-12-01 to 2024-11-30	PTDC/FIS-PAR/2679/2021 / Neutrinoless double beta decay search with the SNO+ experiment

Neutrino

Overview

The LIP Neutrino Physics group currently participates in the SNO+ neutrinoless double beta decay experiment at SNOLAB and in the Deep Underground Neutrino Experiment (DUNE) at Fermilab, SURF and CERN. We pursue a common strategy of balancing data analysis of a current experiment (SNO+) with development and R&D for a future one (DUNE).

SNO+ group activities are divided into two main lines of work, each with its own tasks:

- Background characterization and detector calibration
  - Coordination of the analysis of the backgrounds in the current scintillator phase and of studies for the upcoming Te phase. Completed the analysis of partial fill and water data.
  - Measurement of detector model parameters using mainly intrinsic backgrounds. Coordination of the optical calibration group (ended in 2022).
  - Deployment preparation of low energy gamma sources for the scintillator phase.
- Analysis of physics data
  - Antineutrinos: analysis including neutron calibration, the main background (alpha,n) and the antineutrino signals, in all phases of the experiment.
  - Solar neutrinos and two-neutrino DBD: development of analysis methods based on background characterization and energy spectrum fits.

In DUNE, we focus on:

- Far detector calibrations
  - Design and prototyping of a system to produce liquid argon (LAr) ionization tracks with steerable, intense UV laser beams.
  - Interface of the calibration systems with DAQ, slow controls and computing, including design and prototyping of a dedicated electronics board and dedicated control software.
  - Participation in the measurement of the neutron / LAr cross section crucial for the design of a Pulsed Neutron Source.
- ProtoDUNE@CERN commissioning and analysis
  - ProtoDUNE laser calibration systems design, construction, installation, operation, simulation and analysis.
  - ProtoDUNE data analysis: cosmics and beam data, ^{207}Bi calibration source.

Internal SNO+ leadership responsibilities: Partial Fill (VL) and Water phase (NB) Analysis Coordinators; Physics Analysis Coordinator (VL), Antineutrino Physics (SA); Backgrounds (VL); Calibration Source Review Committee leader (JM) and member (VL). In addition we are members of the SNO+ Executive Committee (JM), Analysis Coordination Committee (JM, VL), Middle Level co-coordinator (VL).

Internal DUNE leadership responsibilities: Calibration and Cryogenic Instrumentation Consortium (JM).

Assessment of the past year: objectives vs. achievements

SNO+

In terms of the water and partial-fill phase SNO+ data analysis, we achieved most of the goals we had planned for 2022:

- We published improved limits for the nucleon decay into invisible channels using the low background water data set.
- We submitted the paper with the antineutrino analysis in water data (now accepted by PRL and selected as Editor's Suggestion).
- The first measurement of the ^{8}B solar neutrinos in SNO+ scintillator was published (PANIC2021 proceedings), an analysis driven fully by ASI (PhD student).
- A paper about scintillation directionality is in preparation.
- A paper on anti-neutrino analysis in partial-fill is in preparation, alpha-n analysis is in progress.

Following the completion of the scintillator fill in April 2021, the SNO+ detector underwent a top-up campaign for the addition of the fluor to increase the light response. This operation ended in April 2022. Our group had a large contribution in the data analysis of top-up campaign data and the following full scintillator data ((alpha,n), DBD target-out, background evaluation) and in its coordination (backgrounds, overall analysis). Main achievements were:

- Evaluated the background ingresses in the detector and the correlation with the fluor addition, change of external water and liquid scintillator temperature. Measurement of the intrinsic purity of the scintillator (U).
- Started the (alpha,n) analysis of the full scintillator, full fluor data.
- Developed a binned likelihood fit to extract the double-beta decay half-life of ^{130}Te and evaluated the impact of non-gaussian tails in the region of interest for the neutrinoless double-beta decay search.
- Evaluated the major systematics and their impact on the sensitivity studies by using the scintillator optical model extracted from data and the scintillator's radioactive purity.
- Started the development of algorithms for improving the signal and background separation using ML techniques.

DUNE

In DUNE we have achieved several of our goals related to detector calibration, but the schedule was affected by delays in the ProtoDUNE-HD (Horizontal Drift) detector at CERN.

- We have completed the production of the mechanical parts under our responsibility for the ProtoDUNE-HD detector. In 2022, these were: the laser safety covers for the instrumentation on the top part of the two periscopes; the support and cover for the beam offset optics for periscope 2.
- We have participated in the full assembly and operational tests carried out at LANL, contributing to several corrections and improvements to the periscope design and to the development of the installation and alignment procedures.
- We have participated in the assembly, alignment and installation of the two periscopes at ProtoDUNE at CERN.
- We have coordinated the installation of the four mirror-based alignment targets inside the ProtoDUNE field cage profiles.
- We have made leak-checking tests of the largest rotary stage (RNN800), with an improved procedure, confirming that even with movement the rates obey the DUNE specifications.
- Progressed on the design of the interface electronics between the laser system and the DUNE DAQ and slow control system:
  - Interfaces with DAQ and slow control have now been established
  - Design of the custom electronics for the ionization laser system has been completed and necessary electronics components have been procured
  - Implementation of all software modules for control and monitoring of the laser system, including slow control server and DAQ interface have been initiated
- Implementation of the Calibration Control Software (CCS), allowing to determine the expected laser path based on the periscope position using a detailed CAD rendering of the detector. Besides visualization, the CCS can be used, for instance, to set the periscope position to hit chosen targets (e.g. calibration mirrors) or avoid regions which could be damaged by a direct hit of the laser (e.g. light detectors).
- The software for control of the stepper motors for the rotary and linear stages was updated and extensively tested during RNN800 dynamic leak check.
- An opto-electronic switch for hardware protection of the sensitive detector parts from laser radiation was developed and tested.

In addition, we made significant progress, working jointly with colleagues from Brazil, on the simulation of UV laser generated tracks in liquid argon through multiphoton ionization. This required the modelization of the laser beam photon profile and the numerical solution of a set of first order differential equations, optimized through the use of multi-threading. In 2022, we developed the method in 3D, and achieved good agreement with published data.

Project management is also a relevant part of the group's activities.

JM is the Calibration and Cryogenic Instrumentation Consortium Lead, and a member of the Photon Detection System review committee. NB has been part of several review committees of different aspects of DUNE (timing distribution system, DAQ and Database).

Other activities beyond SNO+ and DUNE

In addition to the activities in SNO+ and DUNE the group:

- Continues to work with the international (alpha,n) group, with the goal of publishing a white paper summarizing the current knowledge in the field and to perform cross section measurements at the facilities, currently under commissioning, in Spain.
- Has organized, together with colleagues from the INFN, a DBD workshop in June 2022 in Lisbon, which showed active discussion among the experts of the field with the goal of identifying the best strategies in order to reach the normal hierarchy with future large scale experiments.

Lines of work and objectives for next year

SNO+

The analysis of the stable scintillator data taken in 2022 has shown a reduction in the detected light. To compensate for the light loss SNO+ will be adding BisMSB (a secondary wavelength shifter) to the scintillator in early 2023. A period of background counting will follow, which is crucial to verify that the algorithms for the background/signal separation work as targeted and to correctly identify all the events in the signal region where the 0nu signal is expected. Furthermore, SNO+ will commission the Te purification plant. Our group will play a central role in the analysis of that data, both for the operational decisions leading to the DBD phase, but also with the goal of producing physics results, namely in reactor and solar neutrinos. The specific planned activities are the following.

Calibrations and Background

- Continue to monitor purity, optical quality (light yield, quenching) of the scintillator during BisMSB addition. The earlier we reach a full understanding of the pure scintillator, including radial distribution of the backgrounds, the earlier we can add the components of the Tellurium cocktail.
- Perform an analysis of the major background for the reactor analysis: the (alpha,n) reactions.
- Verify the intrinsic purity of the scintillator, in particular the U-chain purity (at the Ra226 and Th234 level).

Water Phase Analysis

- Complete the few missing papers, namely on solar neutrinos.

Scintillator Phase Analysis

- Publish the reactor antineutrino analysis in the partial filled detector (365 t). Publish a study of directionality for solar neutrinos in liquid scintillator as a function of PPO concentration.
- Continue the analysis to understand the sources of Rn ingress, important also for the following Te addition.The analysis includes the understanding of the (alpha,n) and ^{210}Po sources.
- Continue the development of background rejection techniques and classifiers.
- Continue the preparatory work for the double-beta decay phase with sensitivity studies as a function of cocktail purity, mitigation strategies, and optics effects.
- Continue to expand our scientific links, by being involved with the Snowmass community; complete the writing of the White Paper on (alpha,n) reactions.

DUNE

While in 2023 we expect to still focus on calibration in ProtoDUNE, we will also start design activities for the far detector 1, as well as near-to-far detector event translation studies.

Having completed the major mechanics and optics production and procurement, the focus for the commissioning and operation of the laser system of ProtoDUNE-HD will be:

- Produce and test the custom hardware of the calibration interface electronics (CIB).
- Finish implementing the custom firmware and software of the CIB, both to control the calibration hardware parts, and to communicate with the calibration control software (CCS).
- Complete the development of the CCS, including the user control interface, and the communication modules with the DAQ and CIB.
- Development of the calibration specific DAQ modules to perform data selection and monitoring.
- Development of a method to align the periscopes using the mirror-based targets built by our group in the previous years.
- Development of detailed data-taking plans with the full laser system.
- In parallel to that, we will continue to develop a detailed laser ionization model (that we expect to submit for publication in 2023), that will later be used to compare to the ProtoDUNE data, with the goal of developing charge-based calibrations (as opposed to position-based only).
- We plan to initiate an activity to study the response of LArTPCs with Bi2017 sources, in collaboration with CERN colleagues.

Medium-term (3-5 years) prospects

Our medium term prospects for the SNO+ activities are to continue shifting our focus towards physics analyses, while maintaining our responsibilities in the calibrations support analyses.

During the 3-5 years period we expect to collect SNO+ data with different target materials: pure scintillator in 2022-2024, and Te-loaded scintillator from 2024 onwards, at different concentrations. This will allow for a diverse range of physics topics, from reactor antineutrino oscillations, geo and solar neutrino physics, and the first DBD search analyses.

In terms of the participation in DUNE, our medium-term focus is ProtoDUNE, with a set of inter-related activities in tests of calibration system prototypes, DAQ and operations, and analyses of cosmic and beam data. We will focus on designing the far detector calibration systems using: LAr ionization laser beams, to measure electric field distortions and charge response; a set of fixed radioactive sources to track the time evolution of that response; and an external pulsed neutron source, dedicated to the low energy physics. Operations and data analysis of ProtoDUNE, as well as a new activity on the near-to-far detector event translation, are also strategic goals for the longer-term development of an expertise in LAr detectors and physics at LIP.

SWOT Analysis

Strengths

The main strength of the group is the diverse range of expertise of its members, from low and high energy neutrino physics to nuclear, collider, dark matter and cosmic ray physics. From the technical standpoint, the group has experience in optical instrumentation, mechanical systems, LXe, PMTs, DAQ systems (hardware and software) and programming.

Weaknesses

Two of the group's researchers have non-permanent positions, despite having crucial responsibilities in SNO+ and DUNE. The group has a very "top-heavy" structure. This situation is common to several groups at LIP and we are engaging with coordinated efforts to attract students at the undergrad and MSc level.

Threats

SNO+ is a high-risk, high-gain experiment, specially for the high purity Te-loading. Schedule slippage following difficulties during fill, can compromise the impact of the scientific output in a competitive community.

DUNE is a very large collaboration, internally competitive, and a relevant position of LIP within DUNE is ademanding goal. It can be hindered, for instance, by financial or other difficulties that could affect our commitments to the production of the calibration system prototypes for ProtoDUNE. The lack of students also hinders the ability of the group to build critical mass within the experiment.

Opportunities

The SNO+ phase of data-taking and physics analyses with scintillator provide excellent opportunities for Master's theses, potentially attracting new students.

The relatively recent participation in DUNE balances the current participation in the analysis of SNO+ with contributions more tied to technology and instrumentation, and therefore expand the portfolio of the group.

The group's funding situation is presently good, with two ongoing projects: a 3-year PTDC project for SNO+ and a 2-year CERN-fund project for DUNE calibrations.

Publications

3 Articles in international journals (with direct contribution from team)

- *"Techniques for TPC Calibration: application to liquid Ar-TPCs"*, J. Maneira for the DUNE Collaboration, Particles 2022, 5(1), 74-83
- *"Improved search for invisible modes of nucleon decay in water with the SNO+ detector"*, SNO+ Collaboration, Phys. Rev. D 105, 112012 (2022)
- *"Low-energy physics in neutrino LarTPCs"*, S. Andringa et al (subset of DUNE Coll.), J. Phys. G: Nucl. Part. Phys. 50 033001 (2023)

3 Articles in international journals (with indirect contribution from team)

- *"Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC"*, A. Abed Abud et al. (DUNE Collaboration), JINST Vol. 17 Issue1, P01005
- *"Low exposure long-baseline neutrino oscillation sensitivity of the DUNE experiment"*, DUNE Collaboration, Phys. Rev. D 105, 072006
- *"Scintillation light detection in the 6-m drift-length ProtoDUNE Dual Phase liquid argon TPC"*, DUNE Collaboration, Eur. Phys. J. C 82 (2022) 618

1 LIP Students Note(s)

- *"Geo-neutrinos"*, Margarida Ferreira, LIP-STUDENTS-22-19

Presentations

1 Oral presentation in international conference

- *"The SNO+ Experiment"*, Nuno Barros, 2022-06-06, Double-beta decay: the road to normal hierarchy sensitivity, Lisbon, Portugal

1 Oral presentation in national or International Meeting

- *"Neutrino Physics: SNO+ and DUNE"*, Jornadas LIP 2022, Coimbra

Organized Events

1 International Conference or Workshop

- *"Double-beta decay workshop"*, Lisbon, 2022-06-06 to 2022-06-07

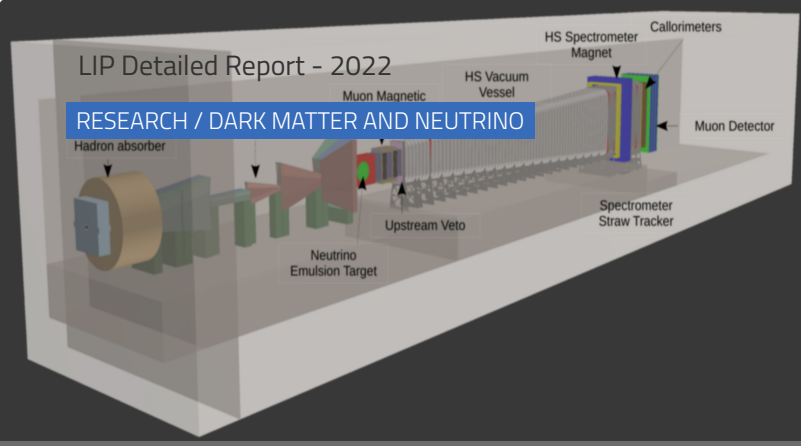
Theses

3 PhD

- Ana Sofia Inácio: *"Measurement of the 130 Te Two-Neutrino Double Beta Decay Half-life with the SNO+ Experiment"*, 2018-03-01 / 2022-11-21, (finished), FCUL, Supervisor(s): José Maneira, Valentina Lozza
- Matthew Cox: *"Background characterisation for water and scintillator phases of SNO+"* (ongoing) and Valentina Lozza
- Wallison Campanelli : *"Characterization of liquid argon detectors for next generation neutrino physics"*, 2022-10-01 , (ongoing), FCUL, Supervisor(s): José Maneira, Fernando Barão

2 Master

- João Carlos Antunes: *"Particle reconstruction in large liquid scintillator detectors using charge and time signal modelization - the SNO+ neutrino physics experiment"*, 2020-11-02 / 2022-12-07, (finished), IST, Supervisor(s): Fernando Barão, José Maneira
- Joana Vences: *"Next-generation Neutrino Physics: Development of the DUNE laser-based Calibrations"*, 2022-09-19 , (ongoing), FCUL, Supervisor(s): José Maneira



SHIP/SND@LHC

Search for Hidden Particles

Principal Investigator:
Nuno Leonardo (35)

5 ***Researcher(s):***
Alberto Blanco (25), Cristovão Vilela (*), Paula Bordalo (30), Paulo Fonte (20), Sérgio Ramos (30)

2 ***Technician(s):***
João Saraiva (20), Luís Lopes (5)

1 ***PhD Student(s):***
Guilherme Soares (100)

1 ***Master Student(s):***
Henrique Santos (14)

4 ***Undergraduated Student(s) and Trainee(s):***
Beatriz Candeias, Bruno Semião, Pedro Figueiredo, Rui David Santos

Total FTE:
2.9 (PhD 1.5)

(*) Starting in December 2022

Articles in international journals:	**2** Direct contribution **1** Indirect contribution
Notes:	**2** LIP Students notes
Proposals:	**1** Proposal(s) and related studies
Nat.& Internat. meetings:	**4** Oral presentation
Collaboration meetings:	**5** Oral presentations
Advanced Training Events:	**5** Oral presentations **3** Student presentations
Outreach seminars:	**2** Seminars

Executive summary

Neutrinos are weakly interacting particles, and despite being among the most abundant in the universe their nature remains elusive. For better understanding their nature and role, we need to better understand how neutrinos interact with other particles. The search for particles beyond the SM with feeble interaction strength is compelling. Theoretical scenarios that extend the SM for addressing dark matter and many other aspects of fundamental physics contain such feebly interacting particles, or FIPs.

The search for feebly interacting particles provides a vibrant experimental endeavour in the pursuit of new physics beyond the standard model (SM). The observation of collider neutrinos will be a milestone that shall open up novel avenues in the investigation of the flavour sector and a new era of neutrino physics at particle colliders. The aim is to contribute in novel ways to the exploration of the full physics potential of the LHC and beyond.

SND@LHC is the most recent CERN experiment. It is designed to exploit the potential of the LHC as a neutrino factory and perform measurements with all neutrino flavours. It shall provide first observations of collider neutrinos, and in a hitherto unexplored energy and kinematic range. It should facilitate unique heavy flavour measurements and further allow the search for FIPs. LIP is a founding member of the new CERN collaboration.

SHiP is a next-generation experiment proposed at CERN, being designed to search for FIPs and to measure neutrinos. SHiP constitutes a general-purpose intensity-frontier experimental infrastructure that will facilitate a flagship program for a comprehensive investigation of the hidden sector of particle physics in the GeV mass domain. It offers high sensitivity for the discovery of FIPs, in a wide unexplored range of their masses and couplings, arising in various portals mediating the SM and dark sectors. The physics program of SHiP encompasses a SM precision component, involving heavy flavour and neutrino physics, specially allowing for a unique study of the tau neutrino. LIP is a proponent of the project.

The LIP group has been centrally involved in the construction and commissioning of the SND@LHC detector, and in data taking and analysis, as well as in the preparation of the SHiP experiment. The tasks of the group are achieved in a close collaboration between the Lisbon and Coimbra nodes of LIP.

The year of 2022 saw the installation of the fully assembled SND@LHC detector in the TI18 tunnel, in time for the start of LHC Run 3, along with its efficient operation and accumulation of first physics data. A proposal has been submitted for the installation of BDF/SHiP, with re-optimised layout, in the ECN3 high-intensity beam facility at CERN. An FCT-awarded funding project, and a PT-CERN PhD fellowship were initiated. A new researcher joined the group and LIP. Four undergraduate students initiated research projects and one MSc student has also joined the group.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Nuno Leonardo (Alberto Blanco)	FCT	40.000 €	2022-03-04 to 2024-03-03	CERN/FIS-INS/0028/2021 / LHC-SND - Participation in the CERN SND@LHC experiment

SHiP/SND@LHC

Overview

The ambition of the group is to contribute in novel ways for probing the standard model and for searching for the new physics beyond, through involvement in the design, construction and physics exploration of dedicated experiments, at the LHC and beyond. The physics focus is on flavour, neutrinos and FIPs.

Heavy flavour is produced abundantly in high energy and high intensity hadron interactions (fixed target and collider). Heavy flavour decays are in turn a source of neutrinos and other FIP states, which can then be detected and studied. The detection of such feebly interacting states is challenging, requiring dedicated experimental instruments and techniques for signal identification and background rejection.

SND@LHC, the Scattering and Neutrino Detector at the LHC, is the most recent LHC experiment, at CERN. It is a compact and stand-alone experiment designed to exploit the high flux of energetic neutrinos of all flavours from the LHC. Following a first observation of collider neutrinos, it shall perform measurements of all three neutrino flavours, in an unprobed energy range (350 GeV to 10 TeV), and associated heavy flavour measurements, in an unprobed rapidity region ($7.2 < \eta < 8.4$), along with searches for FIPs. The detector stems from SHiP's neutrino detector, and is located 480 metres from the ATLAS interaction point and offset from the pp collision axis.

SHiP, the Search for Hidden Particles experiment, is a medium-term endeavour, designed to search for FIPs, exploring the hidden sector of particle physics and neutrinos, in a region of phase space that is largely unexplored. It aims at taking full advantage of the opportunities offered by the available but unused $4x10^{19}$ protons at 400 GeV at the CERN SPS.

The LIP group carries out activities in both detector development and physics analysis fronts. Following preparatory work for SHiP on both of these fronts, in the last two years the focus has been placed in the construction, commissioning and calibration of SND@LHC.

Assessment of the past year: objectives vs. achievements

The year of 2022 has been remarkable for the group and the experiments. The construction and installation of the SND@LHC detector was successfully accomplished, in time for the start of LHC Run 3, and its first physics dataset has been efficiently accumulated. Following detector construction, in which the group was centrally engaged, the focus was placed on its commissioning. The group has been further integrated through active participation in different areas within the new collaboration. Importantly, it has attracted new colleagues, both researchers and students. The execution of a first funding project associated with SND@LHC has been initiated.

The priority involvement of the group for this year, as had been anticipated in last year's report, was the SND@LHC experiment. SHiP related studies were also continued, including through synergies in detector development (prototype testing and integration in different projects) and advanced training activities (internship projects, hands-on tutorials, demonstrations in university courses). One recent study (Summer 2022) explored HNL (heavy neutral leptons) simulated signals decaying to different channels but with identical reconstructed final states. Discriminating variables were explored and used to train machine learning (ML) algorithms (NN) for distinguishing amongst the decay channels, and furthermore to separate the signals from a common background, arising from DIS neutrino interactions (occurring in the detector's decay vessel, and simulated with Genie and Pythia).

The activity in SND@LHC spanned commissioning, data taking, validation, analysis, and upgrade studies. A brief description is provided next.

The bulk of the detector construction took place in 2021, with our direct involvement in the muon system (MS; both upstream and downstream components), and the installation of the whole detector was accomplished in time for the LHC collisions in Spring 2022. It also became clear that its calibration required a dedicated **test beam** campaign, for which purpose extra detector modules were deemed necessary. LIP has produced the corresponding mechanical frames (2 US and 1DS planes), which were timely delivered to CERN.

In SND@LHC, the MS doubles as a sampling hadronic calorimeter. A main motivation for the forthcoming (3rd) test beam (Spring 2023) is the calibration of the energy measurement with the MS. In addition to the above mentioned detector elements, another critical element is simulation. A new **geometry** was implemented, using GEANT4, that emulates the configuration of the detector that will be employed, thus allowing MC simulations, necessary for the calibration studies with test-beam data.

The **timing calibration** of the detector is crucial for ensuing analysis of the data collected. Both the veto and upstream subsystems are formed of scintillating bars, where each is readout on both sides by 8 separate SiPMs, each of these providing its own timestamp. The timestamps of the hits are crucial in analysing possible neutrino events. The calibration strategy developed in the group involved comparing the timestamp distributions between different channels within a same bar, and ensuring a fitting process that is applicable to the whole system. The work was initiated employing test-beam data and was later applied to a subset of the LHC data. The procedure that has been implemented, and the calibration constants that have been derived, are applicable to all data.

SND@LHC nominally detects neutrinos through their interactions in the detector's emulsion target. In addition, a comparable amount of **neutrino interactions** is predicted to occur in the MS. While the resulting position resolution is lower than that obtained with the emulsion detector, interactions occurring in the first half of the system should still yield signatures that can be distinguished. A study of the efficiency for detecting and identifying such muon neutrino

interactions has been carried out, by generating neutrino events consistent with the expected flux by FLUKA.
The group was actively involved in LHC collision **data taking**. Several group members (4) took part in data-taking shifts. They have served as central shifters, who operate the detector, at CERN. As well as expert shifters (piquets), namely for the muon and veto systems, who take expert action on the detector and advise the central shifter in case of issues. We have also set up the SND@LHC control room at CERN, integrated in the CMS remote centre, used since the start of physics data taking.
The **physics analysis** of the collected data set has been initiated. In particular, a preliminary selection was devised, resulting in a golden sample that yielded the first neutrino candidates detected by SND@LHC.

The group has presented a proposal to install a telescope, based on **sealed RPC** technology, to monitor the muon flux in different angular regions. Such a detector upgrade has been approved by the collaboration, and aims at being installed for operation during the ongoing Run 3.

Lines of work and objectives for next year

The group is and shall remain fully engaged in SND@LHC. The activity spans detector calibration, data taking, and physics analysis, as well as RPC detector installation. Preparation for the envisioned SND@LHC upgrade for HL-LHC will be pursued. Involvement in and support for the submitted BDF/SHiP proposal for installation at ECN3 will be continued.

Following submission of the Technical Proposal (Jan 2021) and approval by CERN's LHCC (March 2021), the construction of the **SND@LHC** detector followed, with the active involvement of LIP. The new collaboration was formalised through a MoU for construction (2021), followed by a MoU for maintenance and operation (2022), signed by CERN and the collaborating institutions. LIP is a founding member, and part of both MoUs. With initial responsibility for the hadronic calorimeter and muon system of the experiment, LIP is fully integrated in the new collaboration. The LIP group will continue to further consolidate and expand its involvement in SND@LHC, in both detector development and analysis fronts.

LIP is a proponent of the **SHiP** experiment, the intensity-frontier facility to operate in beam-dump mode at the CERN SPS. The project and its performance have been well documented, including through a CDS report (2019). The ESPPU deliberation document (2020) recognised BDF/SHiP as one of the front-runners among the proposed new facilities at CERN. To respond to financial constraints that prevented approval in 2020, R&D has been pursued to review the design, aiming at implementation in an existing beam facility. The ECN3 high-intensity beam facility has been identified as the most suitable, sensitivity studies for the revised detector layout have been updated, and a proposal has been submitted (2022) to SPSC. The LIP group has an established involvement in the SHiP experiment, in both detector development and analysis fronts. As one of the project proponents, the group will continue to support and actively contribute to the discussion of the proposal for ECN3, which is foreseen to take place during 2023. Refinements to the proposed planning, in terms of prototyping, update to foreseen costs, work packages and timeline towards construction of the proposed detector subsystems we are involved will be pursued.

Following the start of the SND@LHC data taking in 2022, it becomes crucial on the one hand to guarantee the stability and efficiency of detector operations, while implementing improvements inferred from detailed inspection of the data and subsystems' performance. And, on the other hand, to proceed to a detector-driven understanding of the data, and of potential associated inefficiencies, and the implementation of detector calibrations, thus allowing a robust physics exploration of the data.

Data taking and calibration. Plan to continue the active involvement in data taking and play a central role in detector calibration. Contribute in different tasks to the test beam campaign foreseen for Spring 2023. Including detector construction, data acquisition, simulation and analysis. Extend the timing calibration work, to encompass inter-bar calibration, and attain a robust measurement of timing resolution.

Physics analysis. The thorough analysis of the first physics data set (about 40/fb, collected in 2022) becomes another priority. A preliminary selection based on simple criteria applied to 34 fb^{-1} worth of data resulted in a reduction from 6.5 x 10^{19} to about 2000 events, and in an enriched sample that yielded the first neutrino candidates and event displays. A next step is to automatise and optimise the selection procedure. And further, to gain a thorough understanding of the data, calibrate it, quantify and correct for inefficiencies, improve reconstruction methods, and characterise backgrounds, towards robust physics results. A major goal is to advance a stand-alone neutrino analysis, and possibly first publication, based on the electronic detectors alone. The inclusion of the emulsion data would be a next major addition.

Upgrade. The accurate monitoring of the muon flux around the SND@LHC location is paramount. It would be desirable to have such measurements performed at different angles, and eventually in different locations, in view of future SND@LHC upgrades. The installation of a portable telescope based on the sealed RPC technology has been presented and endorsed by the collaboration. The group will complete the design, iterating with the collaboration for accommodating technical specifications and restrictions, and proceed with its construction and testing. The possibility of installing the detector in the TI18 tunnel with standalone operation, maybe this year, will be pursued. Studies will be conducted in parallel for investigating the feasibility of using alternative front-end electronics (with TagusLIP) that would facilitate its potential integration in the central data acquisition system of the experiment in the coming years.

Involvement in advanced training will continue.

Medium-term (3-5 years) prospects

The SND@LHC experiment will be collecting data during the full LHC Run 3 foreseen until 2025. A primary focus for the next 3-5 years will clearly be the full physics exploitation of the collected data. The experiment is expected to provide first measurements of collider neutrinos. Following the first observations, more complete measurements will be pursued, in the neutrino and heavy flavour sectors. Larger datasets will allow to carry out heavy flavour studies, in a kinematic range not accessible to the other LHC detectors, and searches for light dark matter. Neutrino based lepton flavour universality (LFU) tests will be carried out for the first time, which are particularly relevant in view of the current anomalies detected in collider data. Once backgrounds are sufficiently understood, dedicated searches for FIP signals will be pursued.

Over the next few years the envisioned new projects for the HL-LHC phase will be clarified. These will be pursued by the group in two complementary fronts: SND@LHC upgrades and SHiP/ECN3. Following CERN's decision for the facility that will be installed at ECN3, a TDR phase will follow, with design and prototype studies followed by production. The SND@LHC far-detector ($7.2 < \eta < 8.4$) in TI18 will be upgraded and complemented by a near-detector ($4 < \eta < 5$), the latter tentatively located in the CMS cavern. A proposal for a future forward physics facility (FPF) at CERN is also being considered, where an AdvancedSND detector is also foreseen.

SWOT Analysis

Strengths

The team is formed of researchers with a consolidates path and accumulated expertise in both physics analyses and detector development, including in: the competitive RPC technology; collider and fixed-target; heavy flavour, neutrino, and hidden-sector searches; machine learning. The project demonstrates the ability of consistently attracting new researchers and students.

Weaknesses

While the group has been awarded a first FCT-funded project for SND@LHC, thus formally establishing LIP's involvement in the new LHC experiment, the initial budget that has been allocated is limited, in view of current and planned activities.

Threats

Lack of suitable funding and student support. Increasing participating and operation costs (e.g. contributions to emulsion production). The timeline of SHiP/ECN3 remains unclear.

Opportunities

SND@LHC is a new kind of experiment in particle physics and at the LHC. The experiment extends the LHC physics scope and opportunity. SHiP/ECN3 once approved will be a major player in experimental particle physics. Physics case drawing an explosion of interest, potential to bring significant breakthroughs to the field.

SHiP/SND@LHC

Publications

2 Articles in international journals (with direct contribution from team)

- *"The SHiP experiment at the proposed CERN SPS Beam Dump Facility"*, SHiP Collaboration, Eur.Phys.J.C 82 (2022) 5, 486
- *"SND@LHC: The Scattering and Neutrino Detector at the LHC"*, SND@LHC Colaboration, To be published in JINST arXiv:2210.02784

1 Article(s) in international journals (with indirect contribution from team)

- *"Track reconstruction and matching between emulsion and silicon pixel detectors for the SHiP-charm experiment"*, SHiP Collaboration, JINST 17 (2022) P03013

1 Proposal(s) and related studies

- *"BDF/SHiP at the ECN3 high-intensity beam facility"*, SHiP Collaboration, CERN-SPSC-2022-032

2 LIP Students Notes

- *"First sudies with SND@LHC"*, Bruno Semião, Pedro Figueiredo, LIP-STUDENTS-22-03
- *"Distinguishing decay processes for Heavy Neutral Leptons with Machine Learning at SHiP"*, Rui David Martinho Santos, LIP-STUDENTS-22-30

Presentations

41 Oral presentation(s) in national or international meeting(s)

- Guilherme Soares: *"Towards Intrabar SiPM Time Alignment on the Upstream Muon System"*, 2022-06-15, 9th SND@LHC Collaboration Meeting, CERN
- Nuno Leonardo: *"SHiP & SND@LHC"*, 2022-07-08, Jornadas LIP 2022, Coimbra
- Guilherme Soares: *"Intrabar SiPM Time Alignment on the Upstream Muon System and Veto System"*, 2022-12-13, 11th SND@LHC Collaboration Meeting, CERN
- Alberto Blanco: *"Muon flux monitoring in different angular regions"*, 2022-12-14, 11th SND@LHC Collaboration Meeting, CERN

1 Presentation(s) in national conference(s)

- Nuno Leonardo: *"Anomalies, flavour, neutrinos, at LHC and beyond"*, 2022-07-02, A desafiar os limites da ciencia e tecnologia, IST

5 Oral presentations in advanced training events

- Nuno Leonardo: *"Flavour Anomalies at LHC "*, 2022-05-13, 7th Lisbon mini-school on Particle and Astroparticle Physics, Oeiras
- G.Soares, N.Leonardo: *"New Physics with Machine Learning, Hands-on Tutorial"*, 2022-05-14, 7th Lisbon mini-school on Particle and Astroparticle Physics, Oeiras
- Alberto Blanco: *"Particle detectors"*, 2022-07-11, 6th LIP Internship Program , LIP
- Nuno Leonardo: *"Introduction to LHC Physics"*, 2022-07-12, 6th LIP Internship Program , Lisbon
- N.Leonardo, G.Soares, A.Boletti: *"Data analysis and fitting tutorial"*, 2022-07-14, 6th LIP Internship Program , LIP

3 Student presentations in advanced training events

- Guilherme Soares: *"Measurement of Collider Neutrinos with the SND@LHC Experiment"*, 2022-07-06, 7th IDPASC/LIP Students Workshop, Coimbra
- B.Semiao, P.Figueiredo, G.Soares, N.Leonardo: *"First studies with SND@LHC"*, 2022-09-09, 6th LIP Internship Program Workshop, Lisbon
- R.Santos, G.Soares, N.Leonardo: *"Distinguishing decay processes for Heavy Neutral Leptons with Machine Learning at SHiP"*, 2022-09-09, 6th LIP Internship Program Workshop, Lisbon

2 Outreach presentations

- Nuno Leonardo: *"Anomalies, flavour, neutrinos, at LHC and beyond"*, 2022-07-02, A desafiar os limites da ciencia e tecnologia, IST
- Guilherme Soares: *"Neutrinos com SND@LHC"*, 2022-10-13, 61º PubhD de Lisboa, Lisboa

Theses

1 PhD

- Guilherme Soares: *"Measurement of Collider Neutrinos with the SND@LHC Experiment"*, 2022-01-01 , (ongoing), IST, Supervisor(s): Nuno Leonardo, Alberto Blanco

1 Master

- Henrique Santos: *"Neutrino detection at the LHC"*, 2022-09-15 , (ongoing), IST, Supervisor(s): Nuno Leonardo,

[Detector development for particle and nuclear physics]

RPC

nDet

GasDet

LqXe

RPC

Resistive Plate Chambers R&D

Principal Investigator:
Alberto Blanco (40)

8 ***Researcher(s):***
Andrey Morozov (15), Daniel Galaviz (6), Luís Margato (30), Miguel Couceiro (13), Paolo Dobrilla (25), Paulo Crespo (32), Paulo Fonte (74), Susete Fetal (13)

7 ***Technician(s):***
Américo Pereira (15), João Saraiva (51), Luís Lopes (25), Nuno Carolino (10), Nuno Filipe Silva Dias (7), Orlando Cunha (10), Rui Alves (10)

1 ***PhD Student(s):***
Ana Luísa Lopes (65)

1 ***Master Student(s):***
Jorge Francisco Silva (100)

3 ***Undergraduated Student(s) and Trainee(s):***
Iara Neves, Inês Aires, José Alencar

2 ***External collaborator(s):***
Custódio Loureiro, Filomena Clemêncio

Total FTE:
5.4 (PhD 2.5)

Articles in international journals:	**2** Direct contribution
International conferences:	**5** Oral presentations **3** Posters
Advanced training events:	**1** Oral presentation

Executive summary

Currently the group is focused in three main lines of research, each with specific activities in 2022:

- **RPC-PET:** The HiRezBrainPET RPC-based human brain PET tomograph, the world's first device of its kind, was evaluated, demonstrating a sub-millimeter spatial precision and the ability to create images of brain phantoms.
- **tRPCs and PS-tRPCs:**
  - **fast-timing RPC detectors** (tRPC, using the time of flight technique, TOF) high energy physics experiments, currently HADES and R3B at GSI/FAIR. The new forward TOF detector for HADES (RPC-TOF-FD) built and installed by the LIP group run for six weeks with its temperature increased to improve count rate capability. The new TOF detector for the R3B collaboration was successfully operated at two beam times.
  - **position sensitive tRPCs** (PS-tRPC, with time and position measurement) for muography applications, namely telescopes MuTom (transmission muography in geological structures) and STRATOS (scattering tomography) and innovative readouts (within the RPCInnova project, with direct application in scattering muon tomography). The MuTom telescope was installed at the Lousal mine in 2022 and is collecting data.
- **Autonomous RPCs**: reliable, solar-powered, able to operate outdoors at high altitude, RCPc working in ultra low gas flow regimes and sealed RPCs. The first 1m² double gap sealed RPC was built.

In addition, the group, has a close collaboration with the Neutron Detector group in the development of RPCs for thermal neutron detection. The group is now part of the SND collaboration with the responsibility of building and operating sealed RPCs for the measurement of the background in the SND environment, a perfect first application for this new technology.

In termos of funding, 2022 was a year of project execution and consolidation, after in 2021many of our projects were approved for funding. We have successfully concluded projects HiRezBrainPET and RPCAdvance and started RPCInnova (see table below). In addition, we participated in several projects with other LIP groups:

- Muography as a new tool for geophysics (EXPL/FIS-OUT/1185/2021) with the MuTom group.
- SCORE - Short range Correlations on Exotic nuclei at R3R^{3}B/FAIR using tRPCs (EXPL/FIS-NUC/0364/2021) with NUC-RIA group.
- Participation in the SND@LHC experiment at CERN (CERN/FIS-INS/0028/2021) with SHiP/SND@LHC group.
- Fast timing high resolution nRPC-4D detector concept (EXPL/FIS-NUC/0538/2021) with the Neutron Detectors group.

Finally, I am proud to mention that the activities in which our group is involved corresponded to six contributions presented at the 16th RPC 2022 workshop at CERN, in a remarkable variety of topics (which makes us the third largest origin country of RPCs after China and Italy).

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Paulo Fonte		161.255 €	2019-06-17 to 2022-04-16	POCI-01-0247-FEDER-039808 / HiRezBrainPET: high resolution positron emission tomography (PET) neurofunctional brain imaging
Alberto Blanco (Paulo Fonte)	FCT	70.000 €	2020-07-01 to 2022-06-30	CERN-FIS-INS-0009-2019 / RPCADVANCE: Advancement of the RPC detector technology targeting CERN experiments and applications for society
Alberto Blanco		20.000 €	2021-04-01 to 2025-03-31	101004761 AIDAinnova / AIDAinnova
Alberto Blanco (Paulo Fonte)	FCT	70.000 €	2022-07-01 to 2024-06-30	CERN/FIS-INS/0006/2021 / RPCInnova - Advances in RPC detector technology targeting CERN experiments and applications for society

RPC

Overview

The RPC R&D group has its roots in previous work on Parallel Plate Avalanche Chambers done in collaboration with the former Charpak group at CERN. In 1998/9 we participated in the R&D effort for the time-of-flight (TOF) detector of the ALICE experiment, within which we co-invented the timing Resistive Plate Chamber (tRPC) technology. These devices revolutionized the TOF detection technique, opening the way for very large area TOF detectors, essential in many HEP experiments (ALICE, BESIII, BGO-EGG, CBM, FOPI, HADES, HARP, STAR).

Besides the original work in ALICE, we contributed to the field expanding the range of RPC applications, namely: very large area/channel tRPCs; shielded tRPCs for robust multi-hit capability in dense arrays (HADES); use of ceramic materials and warm glass for enhanced count-rate capability; application of RPCs to animal and human Positron Emission Tomography (RPC-PET); simultaneous high-resolution measurement of position and time (PS-tRPCs); very low maintenance, environmentally robust RPCs for deployment in remote locations; large area fast-neutron TOF detectors and position sensitive thermal neutron detectors. In addition to the technological development , we keep an interest in RPC's physics modelling and other fundamental issues, such as gas mixture properties and ageing.

The group have three main lines of work:

1) The **RPC-PET** technology was already applied successfully in a small animal PET scanner used for biomedical research and in a human brain PET, where it reached or exceed the target spatial resolution. The latter has the potential to change the paradigm in the diagnosis and investigation of diseases of the central nervous system, and to play an important role in the characterization of vascular injuries due to its spatial resolution. A full body human PET system, allowing to cover the entire patient within a single-bed acquisition, would increase the overall sensitivity as much as 10-fold. In addition, a physics-limited spatial resolution of 2 mm FWHM is expected across the entire field of view, a figure to be compared with the 4 to 5 mm only in the centre of the field of view of commercial tomographs. Coordinator: P. Fonte.

2) **Timing RPCs (TOF or tRPCs)** continue to be one of the main technologies for the identification of particles (by using the time of flight technique, TOF) in high energy physics experiments when implementation in large areas are needed. In combination with time, the precise simultaneously measurement of the particle position **(TOF-Tracking, or Position Sensitive PS-tRPCs**) is of major interest, since the identification of particles (which relies on timing and position measurements) can be done with a single detector technology without the need to use specific detectors for each task. A direct application of this technology can be found in muon tomography. The spatial resolution achievable (sub-millimetre) and the inherent good adaptation to large areas makes this technology very attractive. Both transmission tomography (e.g. volcano and mine imaging) and scatter tomography (container scanning) are of interest for the group. Coordinator: A. Blanco.

3) **Autonomous RPCs**, able to operate outdoors, reliable, performant, and solar panel powered, are a rather interesting technology for cosmic ray experiments. In particular, sealed RPCs will be a breakthrough in the field, and our group is the world leader. Coordinator: L. Lopes.

In addition to these main activities the group is also involved in the development of High-rate RPCs, Epi-thermal neutron position-sensitive and has collaborations with several LIP groups.

Assessment of the past year: objectives vs. achievements

Objectives as stated in the last report.

1. Evaluation and first human test of the full **HiRezBrainPET** system.
2. Construction and validation of the spare sector of the **RPC-TOF-FD** for **HADES**.
3. **MuTom** operation in the field (inside the mine and at other possible sites).
4. Complete characterization (including efficiency measurement) of RPCs operated in a pressure range from 1000 mBar to 400 mBar with different number/gap-width for the **SWGO** project. The test will be performed with the MAROC board to obtain a complete characterization of the system at equivalent altitudes.
5. Construction of new **sealed RPC** chambers with larger areas. A full instrumented four plane (1*1 m^2) telescope will be produce and tested along the year as a proof of concept.
6. Finalize **RPCAdvance** and start project, **RPCInnova**, focused on ultra low gas consumption and position sensitive timing RPCs.
7. Finalize the integration of the final **STRATOS** station.
8. Continue execution of the **AIDAInnova** project.
9. Operation, calibration and data analysis of the proton TOF within the **R3B** collaboration.

Detailed information on the execution of the 2022 work plan follows:

1. The assembly of the **BrainPET** system took place at the end of 2021 (as described in the previous report) and the evaluation of the scanner characteristics using phantoms was carried out in the beginning of 2022. The most important results are a spatial resolution better than 1 mm FWHM, using a Derenzo phantom or "hot-rod" filled with 18F, which must be homogeneous over the whole field of view due to the precise determination of the interaction depth of the gamma photons inside the detector. This resolution is strongly limited by the photons non-co-linearity effect, with the resolution of the detector, for cosmic rays, being less than 100 um (sigma). This allowed, in a phantom of a human brain with an average activity concentration of 6 kBq/ml and 50 kBq/ml in the striatum, to resolve the striatum chambers, also demonstrating the capability of imaging a realistic brain phantom.

In terms of sensitivity, the scanner shows a central point sensitivity of 0.09%, equipped with less than half of the detectors it can accommodate (due to budget constraints) and affected by a trigger inefficiency that reduces the efficiency by a factor 0.77. Results were presented in the 16th RPC workshop.

2. It was dedided not to build the spare sector of the **RPC-TOF-FD for HADES** in 2022 due to a redefinition of priorities. See HADES group report for more information.

3. The **MuTom** telescope fo transmission muography of geological structures (project "Muography as a new tool for geophysics", EXPL/FIS-OUT/1185/2021) started its operation outside the laboratory as planned. First, in different locations at the Physics Department of UC in order to perform the muography image of the building; and later inside a gallery at the Lousal mine, where it remains at the moment. The remote operation of the detector has been successful, Efficiency and spatial resolution were monitored and remained stable over time (with a residual dependence of the efficiency on gas quality and environmental effects). Results have been presented in the 16th RPC workshop. See the Muon Tomography group report for more info.

4. The characterization of RPCs operated at different pressure values for the **SWGO** project was not carried out due to lack of time. This task is postponed to next year.

5. The work related to **sealed RPCs** has some delay but, during this year, we have assembled a 1 m² double gap chamber (our target size and configuration), which is fully instrumented and in the process of characterization (measurement of time resolution, efficiency and charge spectrum over time), showing a stable performance after a few months of operation. First results were presented in the 16th RPC workshop.

6. The **RPCAdvance** project was concluded with the following main results:

- ***Ultra low gas consumption RPCs***: we have built 2 m² RPCs with new materials (polypropylene) to encapsulate the glass stack, which provide a better barrier to block external agents (atmospheric gases or water vapor). These detectors are able to operate stably with gas flow rates of ~1 cc/min/m², which improves by a factor of two our previous result. Results were presented in the 15th Pisa Meeting on Advanced Detectors.
- ***Position-sensitive timing RPCs***: we have built a 0.1 m² prototype with a position and timing precision of 70 um and 60 ps (sigma). These results are consistent with our previous result but over an area 10 times larger.
- ***High count rate timing RPCs***: we explored the possibility of increasing the detector operating temperature to increase the count rate capability (by reducing the resistivity of the glass, the limiting factor). In-beam measurements, suggest that raising the operating temperature of the detector by 20º (from 20º to 40º) increases the count rate by a factor of 3.5 (from 0.4 to 1.4 kHz), while keeping efficiency (92 %) and time precision (100 ps) without degradation. Results were presented in the 15th Pisa Meeting on Advanced Detectors. We also tested a new low resistivity glass from PICOTech SAS with a promising resistivity of $1x10^9$.
- ***Neutron detector based on ^{10}B converter***: a full optimization, design and construction of an RPC detector for the detection of thermal neutrons was performed. Key aspects were: adjusting the thickness of the boron deposits to match the count rate in each RPC (in order to improve count rate); removal, as much as possible, of hydorgen atoms (causing neutron scattering) by eliminating plastic-based PCB and directly etching the strips on the glass; and use of the low resistivity glass from PICOTech. Unfortunately, due to beam time constraints, the characterization of this detector was not possible within the project, see Neutron detectors group report for details.

7. The **RPCInnova** project started in mid-2022 with the aim of developing ultra-low gas consumption / sealed RPCs and new readout strategies, which achieve both good spatial and timing resolution in large areas (> 1 m²) without the need of a prohibitive number of electronic channels.

8. The **STRATOS** telescope, a four plane 2 m² RPC telescope with an industrial design, exhibits a homogeneous efficiency around 98%, 2D spatial resolution better than 1 cm². Mainly due to the effects of the pandemic, our industrial partner Hidronav has gone bankrupt, leaving the project half-finished (the second station of was not assembled). Hidronav authorized LIP to complete and test the detector. We are currently verifying some stability issues in the front-end-electronics and the gas consumption with the final intention to use the detector for transmission and scatter muon tomography. In the latter modality, preliminary tests (unfortunately with the detector planes not in the final configuration, limiting its capabilities) showed the ability of the detectors to identify high Z materials (e.g. tungsten and lead) after few minutes of acquisition. Results were presented in the 16th RPC workshop.

8. The execution of the **AIDAInnova** project continues, although the activities carried out are not significant at the moment.

9. The TOF wall installed, at the end of 2021 (as described in the previous report), in the **R3B** experiment at GSI, in collaboration with the **NUCRIA** group, within the project EXPL/FIS-NUC/0364/2021: Short range CORelations on Exotic nuclei at R3B/FAIR using tRPCs, was successfully operated in two beam times during the first half of 2022. The detector behaved as expected and calibration and data analysis is currently ongoing. Preliminary results were presented in the 16th RPC workshop. See NUC-RIA group report for more information.

Lines of work and objectives for next year

- The next steps in the development of the **RPC-BrainPET** are: the full evaluation according to the NEMA standards (including timing precision), imaging of human subjects and investigate / demonstrate clinically interesting applications. Moreover, we continue to pursue financial support for the realization of the sensitivity upgrade (installing the maximum number of RPCs) and calibration studies (with the idea of improving the precision) or investigating the lack of sensitivity of the trigger system. Indeed, we have recently submitted a project to the Caixa Research Health Call with a network of Spanish partners with whom we continue to explore new funding possibilities.
- Construction and validation of the spare sector of the **RPC-TOF-FD** for the **HADES** group.
- Continue to support the operation of the **MuTom** telescope.
- Complete characterization (including efficiency measurement) of RPCs operated in a pressure range from 1000 mBar to 400 mBar with different number/gap-width for the **SWGO** project. The test will be performed to obtain a complete characterization of the system at equivalent altitudes.
- The **sealed RPC** project has been combined with the project "CERN/FIS-INS/0028/2021 LHC-SND: Participatin in the SND@LHC experiment at CERN together with the SHiP/SND@LHC group. We have proposed the construction of a small four-plane telescope equipped with sealed RPCs for the characterization of the muon flux at different locations around the SND detector and the validation of beamline simulations, see the SHIP/SND@LHC group report for more details. The goal for 2023 will be the construction, test and operation at CERN of this small device, the first device equipped with sealed RPCs.
- Consolidate the tasks proposed for **RPCInnova**, focused on ultra low gas consumption and position sensitive timing RPCs.
- Finalize the integration of the final **STRATOS** station and explore its capabilities.
- Continue execution of the **AIDAInnova** project.
- Calibration and data analysis of the proton TOF within the **R3B** collaboration.
- Searching for funding for our activities.

Medium-term (3-5 years) prospects

RPC-PET R&D line: We will finalize the evaluation of the human brain PET, trying also to perform the sensitivity upgrade. We would also like to update the pre-clinical small animal RPC-PET with everything we have learned in the HiREzBrainPET project. We will continue to support the PET examinations (using the RPC systems) performed at ICNAS. The effort in the search for new funding in this line is considerable and new projects could emerge.

TOF-RPCs and **PS-tRPCs** R&D line: The existing R&D line for the SHiP experiment is in this moment in stand by, but we have found another application for this excellent detector, the R3B experiment. Our mid-term plan is to have a permanent detector to be used in all the experiments needed. In fact, the characteristics of the detector have attracted attention and it has been proposed to be used in a new series of experiments. In addition, the collaboration is interested in the construction of a larger detector.

Autonomous RPC R&D line: We will continue learning with the MuTom telescope, and accompalying the new developments the project may have. Special effort will be devoted to sealed RPCs with the implementation, for the SND experiment, of the first device to incorporate this type of detectors.

In addition, we want to push forward the fundamental R&D in RPCs, necessary for the improvement of the detectors and to be able to expand their possibilities, namely: operation of RPCs at high altitude and operation with ultra-low gas flux and sealed RPCs. In this context, the project approved by "Fundo CERN", RPCInnova, will be fundamental to advance in this matter and others included in the project.

SWOT Analysis

Strengths

- The team has proven repeatedly to be competent, inventive, productive and reliable. We have access to LIP's technical infrastructures, namely the MW&DL, which have good and experienced staff and a well equipped workshop.

Weaknesses

- The rather small size of the team and their dispersion among many projects. We need to integrate new students or senior members.

Opportunities

- We believe to have, or to be about to have, very competitive detectors ready for applications or technology transfer: small animal and human brain RPC-PET, muon tomography, cosmic ray physics and HEP.
- The human full body RPC-PET application requires a longer and more demanding development, along with funding of the order of millions, but it is potentially hugely interesting.
- The obtained funding in the "Fundo CERN" FCT call will boost the fundamental detector R&D.

Threats

- Unstable funding environment, very much dependent on the calls opening in each year and on their variable strategies. FCT has committed to open regular calls, which would be helpful.
- In the long term, the excessive seniority level of team members will become a problems. Students could contribute to mitigate this.

RPC

Publications

2 Article(s) in international journals (with direct contribution from team)

- *"Concept of a fast neutron detector based on 10B-RPCs"*, A. Morozov, L.M.S. Margato, A. Blanco and D. Galaviz, A. Morozov et al 2022 JINST 17 P02016
- *"Improving count rate capability of timing RPCs by increasing the detector working temperature"*, A. Blanco et al., NIMA 1045, 2023

Presentations

5 Oral presentations in international conferences

- Paulo Fonte: *"An RPC-PET brain scanner: first results "*, 2022-09-26, XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, 26–30 Sept 2022
- Manuel Xarepe: *"Resistive Plate Chambers for Precise Measurement of High-Momentum Protons in Short Range Correlations"*, 2022-09-26, XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, 26–30 Sept 2022
- João Saraiva: *"A Large-Area RPC Detector for Muon Tomography "*, 2022-09-27, XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, 26–30 Sept 2022
- Raul Sarmento: *"Muon tomography with resistive plate chambers for geological characterization"*, 2022-09-28, RPC 2022 - XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, Geneva, Switzerland
- Luís Lopes: *" Outdoor systems performance and upgrade "*, 2022-09-30, RPC 2022 - XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, Geneva, Switzerland

1 Oral presentation in advanced training events

- Alberto Blanco: *"Particle Detectors"*, 2022-07-11, 6th LIP Internship Program, LIP

3 Poster presentations in international conferences

- João Saraiva: *"Advances Towards a Large-Area, Ultra-Low-Gas-Consumption RPC Detector"*, 2022-05-22, PM2021 - 15th Pisa Meeting on Advanced Detectors - Edition 2022, May 22-28, 2022, La Biodola - Isola d'Elba (Italy)
- Alberto Blanco: *"Improving count rate capability of timing RPCs by increasing the detector working temperature"*, 2022-05-22, PM2021 - 15th Pisa Meeting on Advanced Detectors - Edition 2022, May 22-28, 2022, La Biodola - Isola d'Elba (Italy)
- Luís Margato: *"Timing RPC for thermal neutron detection with 3D position sensitivity"*, 2022-09-26, XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, 26–30 Sept 2022

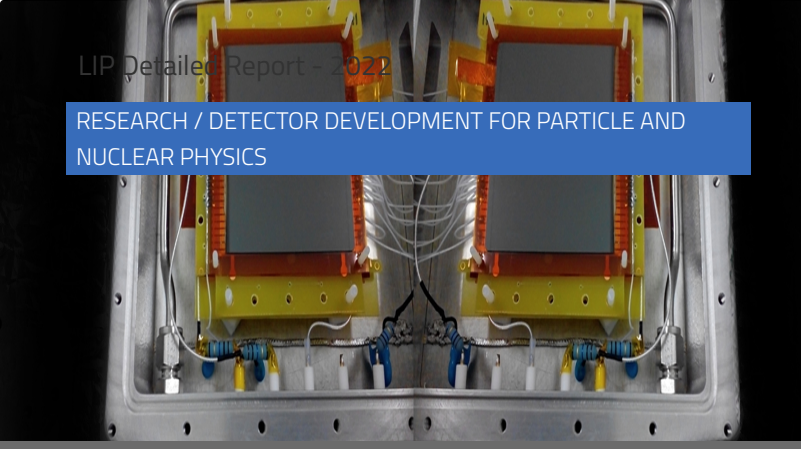
Theses

2 PhD

- João Saraiva: *"A Large-Area Timing & Position Resolution RPC for Muography"*, 2021-09-01 / 2024-09-01, (ongoing), UC, Supervisor(s): Alberto Blanco, Isabel Lopes
- Ana Luísa Lopes: *"Study by simulation and reconstruction of a brain-dedicated positron emission tomograph based on resistive plate chambers"*, 2017-10-02 , (ongoing), UC, Supervisor(s): Paulo Crespo, Miguel Couceiro

1 Master

- Jorge Francisco Silva: *"Transmission muon tomography using ultra-low gas consumption RPC technology"*, 2021-11-08 / 2023-12-31, (ongoing), UC, Supervisor(s): Alberto Blanco, Filipa Borges



NDET

Neutron detectors

Principal Investigator:
Luís Margato (70)

5 ***Researcher(s):***
Alberto Blanco (12), Andrey Morozov (40), Paulo Fonte (10), Vitaly Chepel (20), Vladimir Solovov (20)

2 ***Technician(s):***
João Saraiva (15), Luís Lopes (15)

1 ***Master Student(s):***
Giorgio Canezin (100)

3 ***Undergraduated Student(s) and Trainee(s):***
Carolina Fernandes, Diana Gomes, Inês Serra

1 ***External collaborator(s):***
Luís Pereira

Total FTE:
3.2 (PhD 1.9)

Articles in international journals:	**1** Direct contribution
Notes:	**1** LIP Students note
International conferences:	**1** Poster
Advanced Training Events:	**1** Oral presentation

Executive summary

The Neutron Detectors Group is involved in Detector R&D for neutron detection and has a track record of participating in European projects dedicated to neutron detectors R&D funded by the EU in the frame of FP6, FP7 and H2020 programmes. The group also has an internationally recognized contribution in the development of software tools for neutron detectors simulation and optimization (ANTS2 and ANTS3 toolkits). The main focus is now on the development of a neutron detection technology based on Resistive Plate Chambers (RPCs) and solid neutron converters ($^{10}B_4C$), aiming at high resolution and high count rate position sensitive detectors for cold and thermal neutrons. The first stages of the development were conducted in partnership with ESS (European Spallation Source) and FRMII (Research Neutron Source Heinz Maier-Leibnitz) in the framework of the EU-project SINE2020, and the tests with an early prototype have demonstrated that this is a promising technology.

Presently, the group is developing a fast-timing, high-resolution detector concept (nRPC-4D) providing four-dimensional readout capability (XYZ and time). This activity is being performed in the framework of a project funded by FCT (EXPL/FIS-NUC/0538/2022) and aims at the construction of a demonstrator for the nRPC-4D proof-of-the-concept and its evaluation on a neutron beamline. Applications of this technology are foreseen in TOF (time-of-flight) neutron diffraction/reflectometry, energy- and time-resolved neutron imaging, as well as in other situations requiring readout of position and time. For example, for the next generation MIEZE neutron spin-echo spectroscopy instruments, the required combination of the response time below 1 μs, accurate definition of the detection planes and high 2D spatial resolution is very difficult to achieve with the other technologies.

As a spin-off project, the group is also developing a concept of a ^{10}B-RPC based detector for fast neutrons with a broad energy spectrum (from few keV up to 5 MeV), in collaboration with the NUC-RIA and RPC R&D groups. A potential application for this type of detector is in the measurement of the beta-delayed neutron emission probabilities of very exotic neutron-rich nuclei (e.g. in ISOLDE at CERN). In the near future, the group also plans to perform a feasibility study of the application of the ^{10}B-RPC detection technology for Cosmic-Ray Neutron Sensing (CRNS). The detection of cosmic-ray induced atmospheric neutrons scattered by the nuclei in the air, plants and soil, can be used for environmental applications, e.g., to monitor soil moisture level, enabling more efficient irrigation practices (note that ~ 70% of fresh water use worldwide goes to irrigation) reducing stress on water resources. This application has a strong societal impact, and thus a high potential to attract funding.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Luís Margato (Andrey Morozov)	FCT	49.957 €	2022-01-01 to 2023-06-30	EXPL/FIS-NUC/0538/2021 / Fast timing high resolution nRPC-4D detector concept for neutron science

nDet

Overview

The main purpose of the Neutron Detector group is the development of new detection technologies for neutron scattering science in partnership with the large-scale European neutron facilities such as ILL, ISIS, FRMII and ESS. The R&D activity of the group relies on the extensive expertise in the detector physics, MC simulations, position reconstruction techniques, construction of detector prototypes and detector characterization in neutron beamlines.

The team consists of four core researchers: Luís Margato (coordinator), Andrey Morozov (simulations and data processing), Alberto Blanco (front-end electronics and data acquisition system) and Paulo Fonte (RPC expert). Two students have joined the group: Giorgio Canezin (MSc student) and Carolina Fernandes (who took a Summer Internship and will stay as a research student). Both students are supported by the ongoing FCT-funded project.

The lines of work are:

1) Position-sensitive thermal neutron detectors with TOF capability

Aims to develop the ^{10}B-RPC detection technology in order to be able to meet the strict requirements for detectors used in neutron scattering applications. The main targeted aspects are: detection efficiency, count rate capability, time and spatial resolution, as well as the level of neutron and gamma background.

2) Fast neutron detectors based on ^{10}B-RPCs

Aims to develop an alternative detector concept to the gold-standard one based on the ^{3}He, which is suffering from the forbidding cost of this rare isotope. One of the most promising application areas for such detector is β-delayed neutron emission experiments. It can also be applied for cosmic-ray-induced neutron detection.

3) Software tools for detector simulation/optimization and data processing.

Aims to develop efficient and reliable software tools for designing new detector concepts, detector optimization and processing of experimental data from position-sensitive detectors.

Assessment of the past year: objectives vs. achievements

The objectives established for the year 2022 were:

1. Complete the construction of a ^{10}B-RPC detector in the frame of the RPCADVANCE Project (ended in June 2022) and test it on a neutron beamline at FRMII. The goal was to demonstrate the capability of ^{10}B-RPC neutron detectors in terms of their count rate capability, targeting ~100 kHz/cm^2.

2. Start (January 2022) implementing the project "Fast timing high resolution nRPC-4D detector concept for neutron science". It was planned to design and build a demonstrator for the proof-of-concept. The goal is to demonstrate the capability of the nRPC-4D concept for four-dimensional readout (XYZ coordinates and time).

Regarding the first objective, the manufacturing of the detector's chamber by the Mechanical Workshop and the LIP's Detectors Laboratory was finalized, and the assembly of the detector completed. The detector was tested at LIP using available radiation sources. With respect to its characterization on a neutron beamline at FRMII, an unexpected serious issue forced the shutdown of the reactor, resulting in cancellation of all planned experiments. FRMII is foreseen to restart only in 2024. This hindered the evaluation of the detector count rate capability at a neutron beam, planned for the first half of 2022.

Prof. Florian Piegsa, from the University of Bern, made an offer of beamtime for our group at the Paul Scherrer Institute (PSI) in late 2022, which we accepted. The beam flux at the allocated beamline was however too low to perform the count rate measurements planned in the RPCADVANCE project. We therefore decided to give priority to the tests with the nRPC-4D detector, as there was a straightforward access to a pulsed neutron beam needed for TOF measurements. The most effective management of the available time and resources to reconcile the objective of the count rate studies and the fulfillment of the nRPC-4D project goal, was to retrofit the RPCADVANCE detector with a new design and the new components required for the simultaneous readout of the XYZ coordinates and time, while keeping the characteristics critical for count rate (optimized $^{10}B_4C$ layers thicknesses and glass type) and thus allowing to return to its measurement in a future mission to a high-intensity beam.

Concerning the second objective, the activities planned for 2022 within its three tasks were all completed:

MC simulations and optimization.

A software platform combining ANTS2 (front-end) and Geant4 (back-end) was upgraded to perform comprehensive Monte Carlo simulations of the nRPC-4D detector. Using this platform, an optimal design of the detector prototype was established.

Development of event reconstruction methods.

We have developed a new position reconstruction algorithm utilizing fast Fourier transformation. The performance of the algorithm was compared with that of the centroid-based approach (the gold standard) as well as with the performance of the statistical reconstruction (the best possible quality, but slow) using preliminary experimental data. The results are promising and a paper describing the findings is being prepared.

Detector demonstrator development and characterization.

The design of the nRPC-4D demonstrator was finalized based on the simulation results. The deposition of new batch of $^{10}B_4C$ neutron converters was performed at the ESS.
A new design for the arrays of signal pickup strips for the position

readout was introduced by our group and manufactured by a company as well as the printed circuit boards to hold the front-end electronics and the filters for the cathodes signal, used for timing and for determining the Z-coordinate.

The timing RPCs were assembled and the demonstrator completed. The front-end electronics and the data acquisition system was assembled by the LIP RPC R&D Group.

As described above, the demonstrator was taken to PSI to be tested at a neutron beam. The capability to readout neutron TOF was confirmed; It was demonstrated that the new design of the pickup strips arrays allow to determine the XY position of the detection event, as well as precisely identify the triggered gas gap (Z coordinate); The relative neutron detection efficiencies of all RPCs in the stack was measured and showed good agreement with the simulations.

The count rate capability, spatial resolution, and response uniformity will be measured during the next experimental campaign.

Attracting students

Calls for applications for a MSc student and a research student were announced in the frame of the nRPC-4D project. Giorgio Canezin (MSc) and Carolina Fernandes were selected and joined the group.

As a part of the LIP Summer Internship Program, the group hosted a student who participated in the assembly of the timing RPCs. The results were summarized by the student and published a LIP student note available on the website.

Looking for funding

In 2022, the group joined an EU-Consortium with the leading neutron research facilities of Europe (ILL, ESS, FRM II, PSI and ISIS), in the submission of a proposal, “Neutron Detection 2.0" (Project Nº 101095061), to the Horizon Europe, Call: HORIZON-INFRA-2022-TECH-01. The group led the simulation work package with a budget of 331k€. The project, with total budget of 6.7 million euros was not funded, given the budgetary resources available for the call.

We acknowledge the support of the Albert Einstein Center for Fundamental Physics (AEC) visitor programme at the University of Bern, that covered the accommodation expenses of the LIP team involved in the beam tests at PSI.

Lines of work and objectives for next year

The main focus of the work in 2023 will be to accomplish the objectives of the ongoing project “Fast timing high resolution nRPC-4D detector concept for neutron science” (EXPL/FIS-NUC/0538 /202). The research activities will be organized along two lines:

Detector demonstrator development and characterization.

We will start by finalizing the analysis of the detector characterization conducted during the recent tests at PSI. The main results will be submitted to a peer-reviewed journal.

During these tests we have spotted a problem related to the electronic pickup noise in the fast preamplifiers connected to the RPC cathodes. We will identify the cause and fix the problem. One of the possible solutions is to re-design the fast front-end electronics.

We have also detected notable operational instabilities in the "slow signal" front-end boards and/or in the data acquisition system. With assistance from the RPC R&D Group we plan to investigate this issue. We will start by implementing better shielding between the boards and improving the grounding.

Next we plan to carry out a systematic study of the response of the detector prototype to gamma sources (gamma sensitivity characterization), as well as its sensitivity to the environmental conditions. These experiments can be performed in LIP with the available radiation sources.

We are working to get access to beamtime at a neutron facility (PSI, ILL or at ISIS) in 2023. During the next experimental campaign we plan to focus on the characterization of the detector in terms of the count rate capability, spatial resolution and response uniformity. If a pulsed beam will be available, we will continue the study of the TOF-related capabilities of the detector.

Development of event reconstruction methods

We have already conducted the preliminary tests of the new position reconstruction algorithm based on Fourier transform. The work on the characterization of the algorithm performance will be finalized. For example, we intend to investigate robustness of the algorithm for noisy data in comparison of that of the centroid and statistical reconstruction approaches. We also plan to attempt to reconstruct the spatial response of the detector based only on the calibration with flood irradiation. The results will be published in a peer-reviewed journal.

In addition to these two lines, we intend to conduct an experimental work dedicated to investigation of the dark count background for the new RPCs developed during 2022. Minimization of the background is very important for the spin-off pilot project we have started last year: feasibility study to build fast (up to 5 MeV) neutron detectors with very flat response which have a potential to replace very expensive (~1 M euros) ^{3}He-based detectors in nuclear physics experiments.

Medium-term (3-5 years) prospects

For the next 5 years we define our strategy along the following lines:

- Advancement of the ^{10}B-RPC detection technology to be able to reach with the same detector the spatial resolution of ~ 0.1 mm, the count rate capability beyond 100 kHz/cm^2 and provide TOF capabilities. This will allow to meet the detector requirements for the next generation of TOF neutron diffraction, reflectometry, energy- and time-resolved neutron imaging, as well as in other applications requiring readout of position and time at the spallation sources.
- Define a neutron science application which strongly benefits from our technology and establish a collaboration with a neutron facility to participate in the implementation process. Recently, Florian Piegsa from the University of Bern showed interest in learning more about our technology performance capabilities, in view of an nEDM (neutron electric dipole moment) experiment.
- Continue our recently started efforts to demonstrate the feasibility of building fast neutron detectors based on ^{10}B-RPCs.
- Investigate the possibility of applying our detection technology to Cosmic-Ray Neutron Sensing to monitor soil moisture, and aiming for smarter water management in agriculture. Since projections indicate that by 2050 more than 50% of the world's population will be affected by water stress, and that about 70% of fresh water use worldwide goes to irrigation, it is expected that such technology, if successful, has a major global impact on water security. The societal value of the project has a potential to attract funding.

SWOT Analysis

Strengths

Extensive knowledge of detector physics and experience in the development of neutron detectors and their testing in neutron beamlines at large scale facilities.

Strong background in simulation of particle detectors and development of position reconstruction techniques.

Long-standing collaboration with international partners from world-leading neutron facilities providing access to neutron beam and external funding opportunities.

Weaknesses

Limited human resources. Difficulty in attracting young researchers.

Absence of a neutron source (e.g. ^{252}Cf) in the LIP laboratory in Coimbra for testing detectors.

Opportunities

^{10}B-RPC technology demonstrates a strong potential for applications at large scale neutron facilities. The European Spallation Source is currently driving the development of new types of neutron detectors.

There is an opportunity to test the ^{10}B-RPCs detector on a beamline at ISIS (UK), in collaboration with the ISIS Detector Group.

Threats

No sustainable funding.

Unclear career prospects for the group coordinator (non-permanent position).

Long delays in accessing neutron beamlines threaten planned experimental campaigns, which are crucial for our R&D activities.

nDet

Publications

1 Article(s) in international journals (with direct contribution from team)

- *"Concept of a fast neutron detector based on 10B-RPCs"*, A. Morozov, L.M.S. Margato, A. Blanco and D. Galaviz, A. Morozov et al 2022 JINST 17 P02016

1 LIP Students Note(s)

- *"Development of Hybrid 10B - RPC based neutron detectors"*, Carolina Oliveira Fernandes, LIP-STUDENTS-22-11

Presentations

1 Poster presentations in international conferences

- Luís Margato: *"Timing RPC for thermal neutron detection with 3D position sensitivity"*, 2022-09-26, XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, 26–30 Sept 2022

1 Oral presentation(s) in advanced training event(s)

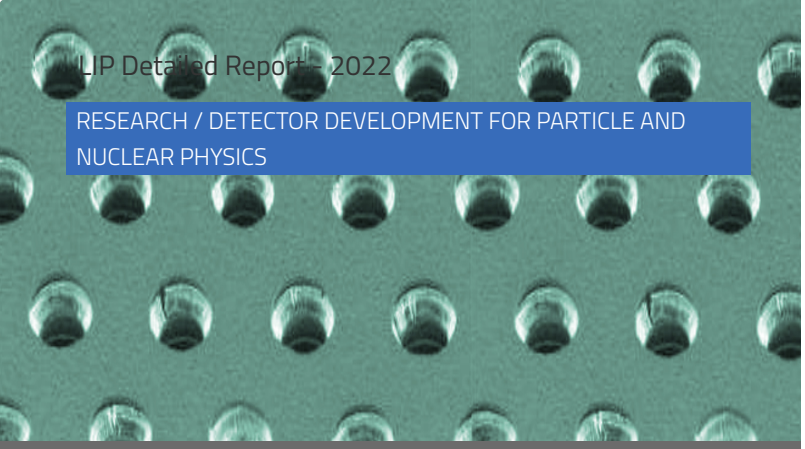
- Carolina Oliveira Fernandes: *"Development of RPC-based neutron detector"*, 2022-09-09, LIP Internship Program 2022, LIP, Coimbra, Portugal

Theses

1 Master

- Giorgio Canezin: *"^{10}B-RPC detection technology for Position Sensitive thermal/cold Neutron Detectors"*, 2022-09-01, (ongoing), FCTUC, Supervisor(s): Luís Margato,

RESEARCH / DETECTOR DEVELOPMENT FOR PARTICLE AND NUCLEAR PHYSICS



GASDET

Gaseous Detectors R&D

Principal Investigator:
Filomena Santos (75)

5 ***Researcher(s):***
Carlos Conde (15), Filipa Borges (85), José Escada (62), João Barata (42), Teresa Dias (30)

2 ***PhD Student(s):***
Afonso Paixão Marques (100), Alexandre Trindade (80)

Total FTE:
4.9 (PhD 3.1)

Articles in international journals:	**4** Direct contribution **1** Indirect contribution
International conferences:	**1** Poster

Executive summary

The Gaseous Detectors R&D Group develops research aiming at the improvement of the performance of gas detectors in the challenging range of low energy (few hundred keV), and more recently also in the higher energy range (few MeV). Its main investigation areas are the study of the drift parameters of charged particles, both electrons and ions (positive and negative), in noble gases and their mixtures used as detector's fillings, with the aim of finding the more suitable medium for each application. In-house developed Monte Carlo simulation codes are developed and used, in parallel with prototypes of gas detectors and experimental systems developed by the group for the measurement of relevant quantities.

The knowledge acquired by the group in the last years allowed to establish international collaborations, namely with the NEXT collaboration that uses a high pressure electroluminescent Xe TPC to search for neutrinoless double beta decay and with the RD51 collaboration that aims at developing new techniques for gaseous detectors with microstructures. In the case of NEXT the group tasks relate to the study and explanation of unexpected observed features occuring in detector testing, namely related to the drift properties and amplification mechanisms in the gas (Xe or Xe dopped with molecular gases). As for RD51, our main work has been the identification of ions formed in mixtures of interest as detection media and on the measurement of ion mobility. In high rate applications the ion formation and their slow motion can be a strong drawback, since the spatial accumulation of charge can change the electric field and the amplification gain. The information on how fast the most abundant ions in a given environment drift from their formation point is an important issue in gas detectors, especially when dealing with new gas mixtures.

Also, the use of negative ions as charge carriers through the use of electronegative dopants in the gas mixture is being considered in experiments using large chambers that depend on track reconstruction, since the ion diffusion during their drift is much smaller than electron diffusion, contributing to a much better defined reconstructed path. The knowledge of the negative ion mobility in mixtures of gases with electronegative dopants is very important for this applications. In addition, since in some electronegative gases several different anions can be formed, the knowledge of the ion mobility of the different anions can allow the determination of the initial interaction point, from the different arrival times. For these reasons the measurement of negative ion mobilities is a novel interest and very important issue. The study of other parameters in electronegative mixtures, such as the efficiency of electron attachment and dettachment to electronegative molecules, and possible signal amplification mechanisms is another study item of the group.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
João Veloso, UA (Filipa Borges)		62.910 €	2022-01-01 to 2024-12-31	PTDC/FIS-NUC/3933/2021 / NEXT: Detection of the neutrinoless Double Beta Decay in Xe-136-the NEXT experiment

GasDet

Overview

There are three main lines of work in our group:

- Ion mobility measurements (positive and negative);
- Study of gas mixtures as detection media and measurement of parameters of interest such as electron diffusion coefficients, both transverse and longitudinal, drift velocities, attachment/dettachment efficiency, scintillation and charge multiplication efficiencies in gaseous mixtures (namely for the NEXT experiment);
- HPXe detector: novel geometries for high pressure gas detectors, with the aim of producing an industrial prototype. This ongoing project has been stalled due to lack of human resources.

Assessment of the past year: objectives vs. achievements

One of the objectives stated in our last report was to improve the dual polarity ion drift chamber. This goal was fully achieved and we now have a reliable and consistent system. Negative ions have been explored. Results for Xe-SF6 mixtures were obtained and presented at Pisa Metting and published in NIM.

Within the scope of the NEXT Collaboration, there were some delays due to the pandemic but, in spite of that, we have published a new paper on primary scintillation yield in xenon and its w-value.

Our PhD student Alexandre Trindade has finished his thesis and is waiting for the defense.

Lines of work and objectives for next year

During the year 2023 our work shall continue within the same lines of work.

Work on negative and positive ion mobililities will continue with suitable candidates for the possible applications, comparing performances among them. Also, various mixture compositions will be tested. Within the framework of the NEXT Collaboration some possible electronegative dopants will be tested and their effect on the other components constituting the working basis of the experiment will be assessed.

Also within the NEXT Collaboration, we will try to answer, interpret and explain unexpected issues that keep arising in the cutting edge and demanding conditions of the experiments. Also, with the new available device, electron diffusion coefficients will be measure for the mixtures considered as candidates for different experiment. The versatility of the system will also allow, with minor changes, for other studies namely testing the effect of devices such as microstructures in the spatial distribution of electrons

Having assessed the validity of the results obtained with our diffusion measuring device we will proceed to measurements in gases for wich there is lack of information and that have been tentatively used in specific applications (e.g.Dimethyl Ether gas, that could be used in gas detectors optimised for polarization studies at low energies).

Within the PhD program of a new student that is focused on the use of electronegative gas mixtures as detection media in detectors, a new branch will be developed in our research. This is quite a novel field. In spite of the fact that several successful applications of negative charge carriers have been reported, a consistent study of the properties of these mixtures considering the different parameters that are important in particle detection,is not available in the literature.

Medium-term (3-5 years) prospects

The objective of the Gas Detectors group for the upcoming years is to develop novel geometries for gas detectors, with the aim of eventually producing an industrial prototype and answer to the needs in the challeging range of high and low energy detection.

Also, we intend to use the knowledge acquired to broaden the scope of our studies, seeking new applications and possible new collaborations. A PhD student is developing a system dedicated to the study of negative ion charge transport at atmospheric and higher pressures to decrease electron diffusion - an important feature in large scale, high pressure, experiments. The study will comprise the effect on electroluminescence and charge multiplication of minor quantities of electronegative dopants in detection gases. This is still an open field of research and can originate further collaborations with groups that are interested in this area, which has driven a large interest in the scientific community, as it may solve some important issues in large scale experiments and also in astrophysics (namely polarimetric studies in the X-ray range). Successful uses of such mixtures have been reported but the understanding of their properties is far from being accomplished.

As a result of the work to improve the accuracy of our experimental results, our data will be used in Monte Carlo packages such as MagBoltz.

A special focus will be maintained on the needs of the NEXT and RD51 collaborations, and new collaborations within our area of expertise will be sought for.

Our Monte Carlo simulation expertize, with custom made and adaptable codes, will also be an unvaluable asset either as a first approach or as a cross check in our lines of work.

Future work for the next five years will also depend on issues that will arise in the collaborations we are part of (namely with the assembly and first tests of the NEXT 100 kg TPC) and also on the available funding and human resources which have been very uncertain in the last years.

SWOT Analysis

Strengths and Opportunities

The group has had the capability to atract students (9 theses, master or PhD, and a few summer internships in the last three years). A crucial aspect for this may be the diversity of skills and tasks offered by the combination of the experimental systems (supervised by Alexandre Trindade, who is now waiting for his PhD defense) and the simulation work developed by the team.

Weaknesses and Threats

The lack of funding will result in the near future in the loss of a fundamental member of our team, that has been responsible for the laboratory work, the supervision of the new students, and that has been with the LIP group for more than 10 years now.

Publications

4 Articles in international journals (with direct contribution from team)

- *"Determination of Ionizing Threshold of Trimethylamine Ions with a High Resolution RGA Mass Spectrometer"*, A.M.F. Trindade, J. Escada, M. Rajado Silva, F.I.G.M. Borges, F.P. Santos, JINST_015P_1221
- *"Dual-Polarity Ion Drift Chamber: A new system to measure the mobility of positive and negative ions"*, D.J.G. Marques, A.F.V. Cortez, M.A.G. Santos, F.P. Santos, A.P. Marques, J. Escada, C.A.N. Conde, F.I.G.M. Borges, NIMA 1029 (2022) 166416
- *"Dual-Polarity Ion Drift Chamber: Experimental results with Xe–S mixtures"*, A. Marques, D. Marques, N. Duarte, J. Teles, A. Cortez, A. Trindade, J. Escada, F. Santos, F. Borges, Nucl. Inst. Met. A, Volume 1045, 1 January 2023, 167575
- *"A new experimental system for electron transverse diffusion measurements"*, A. Trindade, J. Escada, J. Maia, R. Curado da Silva, F. Borges, A. Marques, F. Santos, Nucl. Inst. Met. A, Volume 1045, 1 January 2023, 167603

1 Article(s) in international journals (with indirect contribution from team)

- *"Neutral Bremsstrahlung emission in xenon unveiled"*, C. A. O. Henriques et al., Physical Review X

Presentations

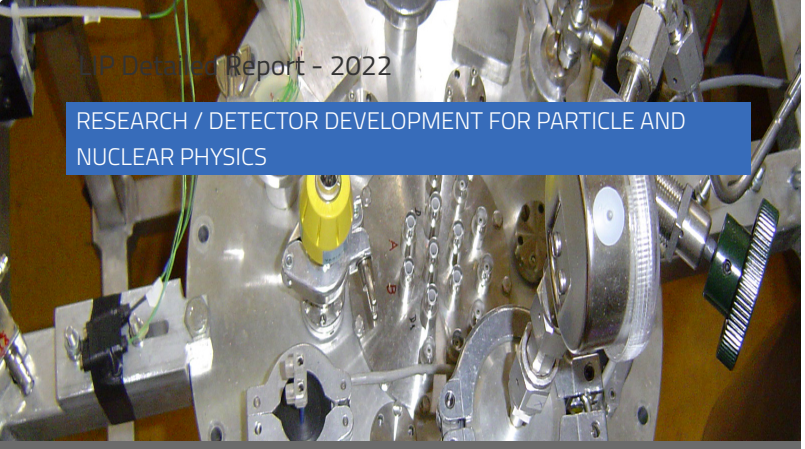
1 Poster presentation(s) in international conference(s)

- Afonso Paixão Marques: *"Dual-Polarity Ion Drift Chamber: Experimental results with Xe-SF6 mixtures"*, 2022-05-22, 15th Pisa Meeting on Advanced Detectors,

Theses

2 PhD

- Alexandre Fonseca Trindade: *"Study of noble gases mixtures characteristics as a detection medium"*, 2016-05-01, (ongoing), UC, Supervisor(s): Filomena Santos, Rui Curado Silva
- Afonso Paixão Marques: *"Transporte de carga por iões negativos em gases nobres com dopantes eletronegativos"*, 2021-09-20, (ongoing), UC, Supervisor(s): Filipa Borges, Filomena Santos



LQXE

Liquid Xenon R&D

Principal Investigator:
Vitaly Chepel (40)

2 ***Researcher(s):***
Francisco Neves (15), Vladimir Solovov (20)

Total FTE:
0.8 (PhD 0.8)

International conferences: **2** Oral presentations

Executive summary

There is a number of experiments around the world using liquid xenon as detector medium. These include search for lepton number violating muon decay, dark matter searches, neutrino physics and double beta decay. Although the energy ranges of interest of those experiment are different, they have very much in common from the detection point of view. The general idea of the group is to carry out research on the processes triggered by particle interaction with liquid xenon as well as on the associated technologies, not being directly involved in any of those experiments. This provides the opportunity for studying fundamental processes in liquid xenon and advanced detection technologies outside the immediate goals of large collaborations, whose work is usually highly focused and tightly scheduled. Such studies may become of significance for the future generation of liquid xenon detectors.

Our area of work is R&D on liquid xenon as detector medium and associated technologies. All electronic, optical and molecular processes, which take place in a single or double phase liquid xenon detector in consequence of particle interaction with the liquid, are in the scope of the activity of this group.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Vitaly Chepel (João Veloso, UA)	FCT	35.000 €	2020-11-01 to 2022-10-31	CERN/FIS-INS/0026/2019 / Participation in the RD51 Collaboration at CERN
Vitaly Chepel (João Veloso, UA)	FCT	35.000 €	2022-11-01 to 2024-10-31	CERN/FIS-INS/0013/2021 / Participation in the RD51 Collaboration at CERN

LqXe

Overview

The general purpose of the group is to carry on R&D on liquid xenon physics and instrumental/technological issues relevant for development of particle detectors based on liquid xenon (and potentially other liquefied noble gases).

The group consists of three senior members, all being PhDs in the field, who equally share the responsibilities and participation in the obtained results.

Its main focus is currently on application of MPGDs (Micropattern Gaseous Detectors) in double phase xenon (liquid/gas) and development of novel methods for the readout of those detectors according to the scientific programme of the RD51 Collaboration at CERN and the FCT grant CERN/FIS-INS/0026/2019 which is the only source of financial support of our activities at present.

Assessment of the past year: objectives vs. achievements

In the past year, the work was focused on completion of the CERN/FIS-INS/0026/2019 project in accordance with the Scientific Program of RD51 Collaboration at CERN having as the main goal contribution to the development and studies of MicroPattern Gaseous Detectors (MPGD). The specific task within this general line was to study a novel method of electron extraction from liquid xenon (and potentially liquid argon) proposed by our group. This method is based on using a multihole two-electrode structure freely floating on the surface of liquid xenon - a Floating Hole Multiplier (FHM). With this idea in mind, two setups have been completed, one at LIP-Coimbra and the other at Weizmann Institute of Science, in the Detector Group, which is our close partner within the RD51 Collaboration. These setups allowed us to carry out two kinds of studies - first, to prove the principle by observing electron extraction from liquid xenon with a floating THick Gaseous Multiplier (THGEM) and, second, to study the behaviour of liquid xenon in contact with a THGEM-like structure at sub-millimetric level. As a result, the novel concept has been proven, the electrons drifting in the liquid were observed to be collected into the THGEM holes, extracted to the gas (in the hole), and to induce secondary scintillation in the gas thus providing the typical S1/S2 signature of an alpha-particle event. As for visual observations, first images have been acquired showing that liquid xenon does penetrate into the holes of a floating FR4 plate, simulating THGEM with different hole diameters from 0.25 mm to 1 mm.

The past year has been also successful in forming a new collaboration for development of novel readout methods for noble liquid detectors and obtaining a small but prestigious 2-year grant from the RD51 Common Fund. The collaboration is led by our group and includes a group from the University of Coimbra and the Detector Group from Weizmann Institute o Science.

Lines of work and objectives for next year

Continue:

1. Microscopic observations of liquid xenon in contact with THGEM and other materials of interest for detector construction. In particular, study the wettability of materials by liquid xenon through attempting to measure the contact angle.

2. Better study electron extraction from liquid xenon through the THGEM holes. Consider optimization of the plate geometry by computations.

Start preparing experiments within CERN/FIS-INS/0013/2021 project, started in November 2022, aiming at measurements of the electron extraction probability from liquid xenon. A novel method has been proposed by us for those measurements. Its technical feasibility should be evaluated.

Medium-term (3-5 years) prospects

Study FHM performance in liquid xenon and possibly in liquid argon (additional material studies will be required for that). Study novel techniques of electroluminescence production in the liquid medium. Address the feasibility of new technologies and their prospects for the next generation noble liquid detectors.

Study electron emission from liquid xenon using the novel method of drifting charge measurement in a double phase system. Extend, if possible the measurements to liquid argon.

The work will be carried out in the framework of CERN/FIS-INS/0013/2021 till 10/2024. Submit a new proposal to the FCT/CERN Fund to enable further studies. Complete the RD51 Common Fund program by the end of 2024. If feasible, apply for a new Common Fund project. Consider participation in the forthcomming DRD1 and DRD2 collaborative initiatives in the framework of ECFA Roadmap for particle detectors.

SWOT Analysis

Strenghts

Highly qualified and internaionally recognized group members with many years of experience in the field of detector development.

Weaknesses

Limited availability of human power. Heavy involvement of the group members in other activities and projects.

Opportunities

The weaknesses overcome, there is an opportunity for sound contributions to the development of liquid xenon detectors and better understanding of the underlying physics in general, and for the development of the next generation of large scale liquid noble gas detectors for rare events in particular.

Threats

Degradation of the experimental basis due to the lack of investment, accumulated for many years in the laboratory.

Presentations

2 Oral presentation(s) in international conference(s)

- V. Chepel, G.Martinez-Lema, A.Roy, A.Breskin: *"Floating Hole Multiplier – a novel concept for dual-phase noble liquid detectors"*, 2022-09-22, LIDINE 2022 - Light Detection in Noble Elements, Sept. 21-23, Warsaw
- Vitaly Chepel: *"A novel concept for dual-phase noble liquid detectors – Floating Hole Multiplier"*, 2022-12-12, MPDG-2022, Rehovot, Israel

[Instruments and methods for biomedical applications]

ORimag

Dosimetry

Advanced Radiotherapy and Charged Particle Therapy Applications

The Prototera Association was established in 2019 to promote and develop a national research and teaching network in advanced therapies and associated technologies in Portugal. The association is committed to enhancing research infrastructures, training, and healthcare associated with the treatment of cancer patients using advanced technologies, specifically in the following areas:

A) Effects of high-energy radiation on biological and material systems; B) High-energy particle beam therapies; C) Theranostics for precision and customized medicine; D) Accelerators, beam lines, planning systems, and imaging; E) Advanced Medical Imaging.

LIP played a pivotal role in creating the Prototera association, along with Técnico, CTN, Universidade de Coimbra, and the Portuguese network of Oncology Institutes. LIP also made internal efforts to bring together groups and researchers developing applications that could lead to technology transfer from Particle Physics and Associated detector development to radiation therapy, particularly cancer therapy with charged particle beams. This effort resulted in the creation of the research theme on Advanced Radiotherapy and Charged Particle Therapy Applications, which integrates two research groups, the Orthogonal Imaging for Radiotherapy Improvement group (ORIMAG), based in Coimbra, and the Radiation Dosimetry Applications to Advance RadioTherapy (RADART), based in Lisbon.

The ORIMAG group has been developing instruments and methods for beam range monitoring in near real time, such as Orthogonal Prompt Gamma Imaging and associated instrumentation, and in the use of Time of Flight Positron Emission Tomography for the same purpose. The RADART group, on the other hand, is involved in the development of high-resolution detectors for dosimetry and Monte Carlo simulations of radiation effects in medical applications and radiation protection.

The interest of students to develop their theses in the field of Advanced Radiotherapy and Charged Particle Therapy Applications has increased in the last years. This interest was greatly supported by the Prototera doctoral Programme, a FCT doctoral Programme coordinated by LIP, which started in 2020 and has awarded grants to 13 students so far, and also to the PT-CERN doctoral programme in the domain of development of technologies associated to the Portuguese participation at CERN and their transfer to society. Along with the interest of PhD students, the interest of Master students in this field has also been considerable, as can be seen by the significant number of students that developed or are developing their theses, in both groups, during the period covered by this report.

The supervision of students by LIP researchers, who are also teachers in Instituto Superior Técnico, Faculdade de Ciências da Universidade de Lisboa and Universidade de Coimbra, proceeds in most cases in co-supervision with experts in the field of Charged Particle Therapy, Radiotherapy or associated areas. In these cases, the students have been awarded mixed grants, that allow for 24 months abroad, in locations where the necessary infrastructures, charged particle treatment facilities, exist, such as DKFZ in Heidelberg, ICPO in Orsay or CMAM in Madrid.

In the past years LIP has thus been following a strategy aimed at providing advanced training in the field of radiotherapy and particle therapy applications of physics to increase expertise in Portugal in these fields, particularly in support of a future Portuguese charged particle therapy facility. However, the future of the charged particle facilities for cancer therapy in Portugal is presently undefined. For this reason, LIP has outlined a new strategy that aims to put together two different activities: one directed outwards and another directed inwards.

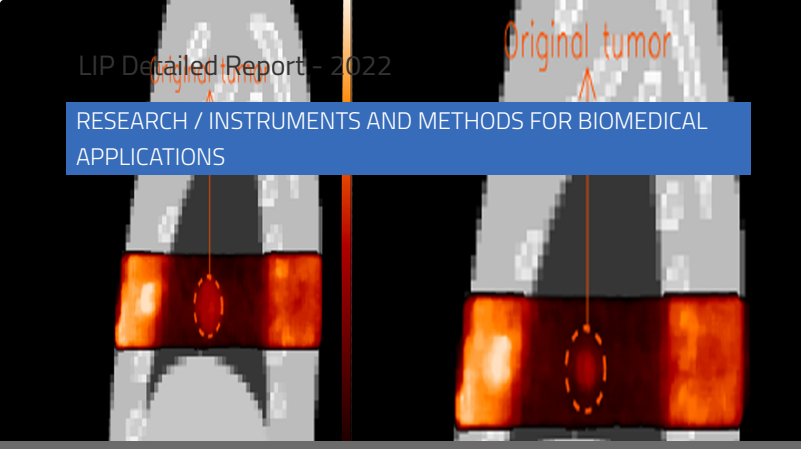
The first strategic orientation is the intent to push forward an International Network for Advanced Radiotherapy, in which LIP will promote with its partners the advanced training of physicists, medical physicists, and clinicians at Iberian and European level. This strategy aims at exploring the opportunities that arise from the foreseen installation of 13 proton therapy facilities in Spain in the next years, on top of the already existing two facilities in Madrid, and the collaborations that have been put in place throughout Europe, in particular with the Prototera Doctoral programme.

The second strategic activity is directed inwards, towards the creation of a Radiation Engineering Centre at LIP for advanced training in the application of ionizing radiation to different fields (health, materials, and space). This would enable LIP to consolidate its efforts in the development of charged particle therapy applications, enabling LIP's contribution to advances in

the field, and it would also contribute to the creation and support of scientific and technical employment at LIP. In addition, a Radiation Engineering Centre at LIP would reinforce its role in the planned International Network for Advanced Radiotherapy.

The main objectives of the thematic line are thus: (1) to create critical mass at LIP to develop advanced applications that can support radiotherapy and Charged Particle Therapy, thus enabling technology transfer from "traditional" LIP areas to advanced radiotherapy applications; (2) to contribute to the development of innovative tools and methods that can improve the state of the art in Advanced radiotherapy; (3) to contribute to the development of a Radiation Engineering Centre at LIP; (4) to be a vehicle for the integration of Portugal in research and training networks in the fields of radiotherapy and charged particle therapy at Iberian and European level.

RESEARCH / INSTRUMENTS AND METHODS FOR BIOMEDICAL APPLICATIONS



ORIMAG

Orthogonal Ray Imaging for Radiotherapy Improvement

Principal Investigator:
Paulo Crespo (65)

6 ***Researcher(s):***
Andrey Morozov (40), Hugo Simões (100), Jorge Sampaio (30), João Gentil (15), Patrícia Gonçalves (38), Pedro Assis (15)

2 ***PhD Student(s):***
Duarte Guerreiro (35), José Patuleia Venâncio (100)

5 ***Master Student(s):***
António Carvalho (27), António Sampaio (50), José Pedro Teodoro (70), João Costa Silva (50), Margarida Simões (50)

1 ***External collaborator(s):***
Carolina Bugalho

Total FTE:
6.8 (PhD 3.0)

International conferences:	**4** Posters
Nat.& Internat. meetings:	**1** Oral presentation
Advanced Training Events:	**2** Oral presentations **1** Student presentation
Completed theses:	**3** MScs

Executive summary

The work of the OR Imaging group is divided into two main branches related to proton theraphy monitoring:

(1) O-PGI: orthogonal prompt-gamma imaging, for monitoring proton therapy treatments, a collaboration between LIP and the University of Coimbra; and

(2) the activities within the TPPT consortium (in-beam time-of-flight PET for monitoring proton therapy), a consortium between LIP, the University of Coimbra, PETsys Electronics in Lisbon (the leading company), the University of Lisbon, the University of Texas at Austin, TX, USA, and the MD Anderson Cancer Center, in Houston, TX, USA.

A third line of research, OrthoCT, concerns external X-ray radiotherapy: orthogonal computed tomography, for monitoring external, megavoltage-based radiotherapy (i.e. high-energy X-rays), which is a collaboration between LIP, the University of Coimbra, the Radiotherapy Department of Coimbra University Hospital Center, and the Porto Oncological Center Francisco Gentil, E.P.E. (IPO-Porto).

Regarding O-PGI, the group continued two previous GEANT4 studies. In [Cambraia Lopes et al., Physica Medica 2018] we reported simulation results with several multi-slat collimated systems designed to assist both head-and-neck as well as pelvic irradiations. However, a perfect detector was used as particle detector. In [Morozov et al., Physica Medica 2021] we presented a study where scintillation crystals were used as particle detectors. This study demonstrated an edge detection precision of 2 mm full width at half maximum (FWHM) for 130 MeV proton beam irradiation. But a homogeneous phantom made of acrylic glass was used as a target.

During 2022 the simulation work was performed along two main lines: (1) simulation of a full system for assisting head irradiation of an anthropomorphic phantom, including scintillator crystals for detecting the orthogonal prompt-gamma rays; and (2) simulation and optimization of a multi-slat prompt-gamma camera for 200 MeV proton beam distal edge determination (i.e., typical energies used in pelvic irradiation). The edge detection precision of both studies remained at 2 mm, achieved by using time-of-flight and/or energy discrimination techniques to reject neutron-induced secondary gamma rays. The results obtained were reported in three presentations at international conferences. Two Masters students were and one PhD student is involved in these studies. In the experimental field, a small-scale prototype is currently being built at LIP facilities. It consists of four slats of tungsten interleaved with three rows of YAP scintillators. We plan to test it later this year in a clinical proton cyclotron in Delft, the Netherlands (HollandPTC).

In what concerns our simulation engagement with the TPPT consortium, during this year, the work was performed along three main lines. (1) Update of the GEANT4-based framework developed for comprehensive simulation of the dual-head TOF-PET system; (2) Upgrade, refactoring and optimization of the procedure for building a voxelized anthropomorphic phantom based on the computed tomogram (CT) of a patient; and (3) development of a fast ("probability-based") approach for generation of Positron Emitting Species (PES). Two master students were engaged in part of these activities. The overall goal is to obtain a system that can simulate the activity induced in the head of a patient during a proton treatment, feeding its spatial and time distribution into a reconstruction routine being developed by a team of the University of Coimbra (outside LIP). Another goal is to provide simulated data to support experimental results to be acquired soon at the MD Anderson Cancer Center, in Houston, TX, USA, by our consortium partners.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Paulo Crespo (Patrícia Gonçalves)		222.004 €	2020-01-01 to 2023-06-30	LISBOA-01-0247-FEDER-045904 / TPPT - Time of flight PET for Proton Therapy
Paulo Crespo (Patrícia Gonçalves)	FTC	90.000 €	2022-01-01 to 2023-12-31	CERN/FIS-TEC/0017/2021 / ImprovingPT: Optimization, construction and first in-beam tests of range monitoring and quality assurance systems for the improvement of proton therapy

ORimag

Overview

The research developed by the OR imaging group is part of LIP's core projects in instrumentation for radiation therapy. It is developed in partnership with a Portuguese Oncology Institute, the Hospital of the University of Coimbra, and several medical research centers in Portugal and abroad. The aim is to improve radiotherapy by optimizing the treatment in near real time, so that the irradiation can better accommodate the tumor and spare surrounding healthy tissue. To do this, we use X-ray irradiations (OrthoCT), or gamma rays from proton irradiations (O-PGI) emitted orthogonally to the treatment beam. Since January 2020 we are partners in a consortium (Portugal Austin) aiming at establishing the in-beam TOF-PET technique into one of the beamlines for proton therapy at MDACC (MD Anderson Cancer Center in Houston, TX, USA).

LIP is a founding member of the ProtoTera Association, created to promote the development of a national research network in advanced therapies and associated technologies to treat cancer patients. In the context of this interdisciplinary development, the OR Imaging group is part of the following funded projects:

- Optimization, construction and first in-beam tests of range monitoring and quality assurance systems for the improvement of proton therapy, in collaboration with the LIP Dosimetry group (CERN fund, between January 2022 and December 2023).
- TOF-PET for Proton Therapy (TPPT), in the framework of the Portugal-Austin collaborative projects, led by PETsys electronics and involving several other institutions in Portugal and in Texas, USA. Fund granted between January 2020 and June 2023.

As an example of recent progress in O-PGI studies, a multi-leaf collimator was fully optimized using extensive GEANT4 simulations and our own reconstruction routines. Even in (simulated) situations where oedematous tissue may account for a Bragg peak shift as small as 2 mm, the final results yielded an O-PGI system capable of discriminating clearly such shift in a homogeneous phantom of acrylic. Similar results were obtained with an anthropomorphic phantom. Work is ongoing to build and test a small scale prototype.

Concerning our contribution in the TPPT consortium, recent developments have made it possible to reduce the simulation time by three orders of magnitude, either by implementing a probability-based method for generating positron emission species or by redefining the geometry of the voxelized phantom. Improvements in this direction are needed to reduce the high computational cost of Monte Carlo simulation.

Assessment of the past year: objectives vs. achievements

Last year four lines of work were foreseen.

1) OrthoCT: Publish results obtained at the Radiotherapy Department of Coimbra University Hospital Center (first imaging of cavity in homogeneous phantom without rotating the X-ray source or the phantom).

2) O-PGI: full simulation of head irradiation (digital anthropomorphic phantom, O-PGI system includes scintillators and visible light detectors)

3) O-PGI: optimization of a multi-slat prompt-gamma imaging system for pelvic irradiation.

4) In-beam TOF-PET system: full simulation with custom, accelerated simulation code (ongoing)

Task (1) is still ongoing. The lack of funding in this line of research resulted in less resources being allocated to this task.

In what concerns the O-PGI tasks, a full simulation of a head irradiation of an anthropomorphic phantom (2) and an optimisation of a multi-slat prompt-gamma imaging system for pelvic irradiation (3) were performed. In both studies, the position of the distal edge was achieved with an precision of 2 mm FWHM. These results led to three presentations in international conferences: two at the 2022 IEEE Medical Imaging Conference and one at the 2022 International Conference on Monte Carlo Techniques for Medical Applications. The manipulation of gamma rays from neutron interactions for 200 MeV irradiation was achieved not only by TOF rejection but also by energy discrimination. The results obtained with the 200 MeV irradiation are being prepared for publication. Two MSc students concluded their studies within this line of research: José Pedro Teodoro concluded an MSc. in Biomedical Engineering and worked involved in task 2; and João Costa Silva was engaged in task 3 and concluded an MSc in Physics Engineering,.

Finally, regarding the in-beam TOF-PET system (4): full simulation with custom, accelerated simulation code was achieved by manipulating the DICOM patient-based phantom geometry and by implementing a probability-based method that uses look-up-tables, as suggested by one of our collaborators, for generating positron emitting species. By manipulating the phantom geometry, the number of pixels was reduced by a factor of 10, speeding up the simulation and reducing the RAM requirements (essential when running on computer clusters). The probability-based method allowed to reduce the simulation time by three orders of magnitude .Margarida Nunes Simões completed her MSc in Medical Physics in this line of research.

Lines of work and objectives for next year

In the framework of the ongoing projects, the following lines of work and objectives are defined for 2023:

1. OrthoCT: Summarize and submit for publication the experimental results obtained with megavoltage X-ray irradiation at CHUC.

2. O-PGI:

2.1 Construction of a small prototype detector consisting of four slats of tungsten interspersed with slats of YAP scintillators (ongoing, to be completed in a time span of half a year).

2.2 Prototype testing at the clinical proton cyclotron in Delft, The Netherlands (HollandPTC).

2.3 Investigation by simulation of the capability of the orthogonal gamma rays to detect dose deviations during fractionated craniospinal irradiation of paediatric patients (a trainee will join the team to carry out this task)

3. In-beam TOF-PET

3.1 Full simulation (patient CT converted into anthropomorphic phantom, together with simulation) with custom, accelerated simulation code (continuation).

3.2 Cross-validation of the custom, accelerated simulation code with the full Monte Carlo (GEANT4) simulation

One MSc student (António Carvalho, MSc in Biomedical Engineering) and one PhD student (José Patuleia Venâncio, PhD in Physics Engineering) are developing their theses within these lines of work (see theses list at the end of the group report).

Medium-term (3-5 years) prospects

If funding is granted, building an O-PGI system for head-and-neck and pelvic irradiation (should the two systems be compatible into one unique realization) is envisaged. This includes devising the optimum readout strategy for the system: SiPM, arrays of avalanche photodiodes, fibre optics coupled to PMTs, or light-guides connected to either one of the aforementioned light detectors.

In a 3-5 years framework we plan having simulated case-studies with enough detail to convince radiation oncologists of the usefulness of both OrthoCT and O-PGI in megavoltage X-ray radiotherapy and proton beam therapy. In each case, we envisage providing evidence of usefulness in a variety of irradiation cases: head-and-neck, pelvis (bone tumor and prostate), lung, craniospinal irradiation in pediatric tumors, among others. In the meantime, we hope to have started a collaboration with a company in order to build these systems and their robotic apparatus in accordance with the specifications obtained from our comprehensive Monte Carlo work.

In addition, we plan including CT-based (computed tomography) data into the simulations so that real treatment plans may also be simulated, with and without pertinent patient (simulated) modifications.

Should an O-PGI system be available, images obtained with real phantoms should also be acquired at a clinical proton therapy site, with and without mimicking patient morphological alterations.

Regarding the in-beam TOF-PET system under construction, in a first stage (up to mid-2023) the imaging of homogeneous, heterogeneous and anthropomorphic phantoms is envisaged. The plan is to apply for a new funding call which will allow us to further explore the applicability of the beta+ activity generated during the irradiation for proton range verification.

We also intend to start a new international consortium to explore the potential of prompt particles produced during proton irradiation in the Bragg peak position determination (proposal recently submitted to a funding call: la Caixa, Spain).

SWOT Analysis

Strengths

The rotation-free, low-dose imaging capability of O-PGI and OrthoCT are two of their strengths. The imaging capability of both techniques have been proven by experiment (OrthoCT) and detailed simulation (O-PGI) in real therapeutic scenarios. O-PGI competes with in-beam time-of-flight PET, the latter highly suffering from biological washout of the produced beta+ activity, which does not affect O-PGI.

Weaknesses

The high out-of-field particle flux existing in a clinical linac force OrthoCT to be surrounded by heavy shielding. This weakness can be surpassed by proper robotic solutions to position the whole detector assembly closer to the patient; nevertheless, they come at non-negligible price. Both O-PGI and in-beam PET suffer from their complexity of detector positioning.

Opportunities

The higher the degree of conformality achievable by means of external beam radiotherapy, the equally higher is the demand for patient imaging just prior (on- board) or during the therapy session, in order to ensure that the high conformal capability of the treatment is reaching its goals (tumor irradiation, sparing of organ(s) at risk or healthy tissue). The three techniques researched in our group represent an added value in both scenarios: on-board and/or real-time patient imaging.

Threats

The investment of clinical sites in other IGRT (image-guided radiation therapy) techniques makes investment in the three pursued techniques questionable for such sites, at least before the return on previous investment(s) is achieved.

ORimag

Presentations

4 Poster presentations in international conferences

- H. Simões, A. Morozov, J. Silva, J. Teodoro, P. Crespo: *"Distal edge determination for a multi-slat prompt-gamma camera: Irradiation with a 200-MeV proton beam"*, 2022-02-11, International Conference on Monte Carlo Techniques for Medical Applications,
- J. Silva, H. Simões, A. Morozov, J. Teodoro, P. Crespo: *"Simulation of a multi-slat prompt-gamma camera for proton beam distal edge determination during pelvic irradiation"*, 2022-11-05, IEEE Nucl. Sci. Symp. & Med. Imag. Conf. (NSS/MIC), Milano, Italy
- J. Teodoro, H. Simões, A. Morozov, J. Silva, P. Crespo: *"Simulation of proton range monitoring in an anthropomorphic phantom using a multi-slat prompt-gamma camera"*, 2022-11-05, IEEE Nucl. Sci. Symp. & Med. Imag. Conf. (NSS/MIC), Milano, Italy
- S.P. Tavernier, R. Bugalho, F. Caramelo, J.P. Cesar, P. Crespo, J.C. Da Silva, L. Ferramacho, N. Ferreira, P. Gonçalves, D. Grosshans, B. Jesus, K. Klein, K. Lang, C. Layden, C. Leong, W. Matava, A. Mozorov, F. Poenisch, M. Proga, N. Sahoo, J. Seco, H. Simões, R. Silva, M. Silveira, J. Varela: *"Positron emission tomography for proton range verification in proton radiation therapy"*, 2022-11-05, IEEE Nucl. Sci. Symp. & Med. Imag. Conf. (NSS/MIC), Nov. 5 - 12, Milano, Italy

1 Oral presentation(s) in national or international meeting(s)

- Paulo Crespo: *"ORimaging group activities"*, 2022-07-08, Jornadas LIP 2022, Coimbra

2 Oral presentations in advanced training events

- Paulo Crespo: *"Hadrontherapy"*, 2022-06-04, Curso Avançado em Imagem Biomédica, Universidade de Coimbra, Portugal
- Paulo Crespo: *"Particle physics techniques applied to health"*, 2022-07-14, LIP Internship Programme Tutorial Week 2022,

1 Student presentation(s) in advanced training events

- José Patuleia Venâncio: *"Prompt-Gamma detection and instrumentation for Bragg Peak monitoring"*, 2022-11-29, 1st Prototera PhD students Workshop, Coimbra

Theses

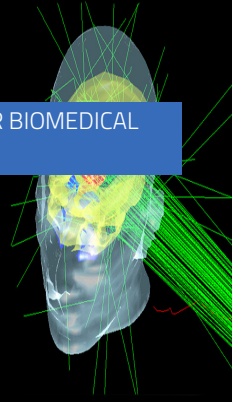
2 PhD

- Duarte Guerreiro: *"Scintillating array for real-time high-resolution ion therapy dosimetry"*, 2020-09-01 , (ongoing), FCUL, Supervisor(s): Jorge Sampaio, Luis Peralta
- José Patuleia Venâncio: *"Bragg Peak monitoring through prompt-gamma: detection and instrumentation"*, 2020-09-01 , (ongoing), IST, Supervisor(s): Patrícia Gonçalves, Pedro Assis

5 Master

- José Pedro Teodoro: *"Proton therapy monitoring with orthogonal gamma imaging: The case of head irradiation"*, 2020-09-14 / 2022-09-13, (finished), UC, Supervisor(s): Paulo Crespo, Hugo Simões
- João Costa Silva: *"Proton beam distal edge determination with a multi-slat prompt-gamma camera for pelvic irradiation"*, 2021-01-01 / 2022-09-29, (finished), UC, Supervisor(s): Paulo Crespo, Hugo Simões
- Margarida Simões: *"Monte Carlo simulation of beta+ radioactivity generation and its imaging with an in-beam PET system for range monitoring in proton therapy"*, 2021-02-01 / 2022-09-30, (finished), UC, Supervisor(s): Paulo Crespo, Andrey Morozov
- António Carvalho: *"Fast algorithms of simulation of the positron-emitting activity generation for multi-beamlet proton therapy treatment plans"*, 2022-09-26 / 2023-09-30, (ongoing), UC, Supervisor(s): Paulo Crespo, Andrey Morozov
- António Sampaio: *"Optimization of a device for deep-brain transcranial magnetic stimulation via simulations"*, 2019-03-22 , (ongoing), FCTUC, Supervisor(s): Paulo Crespo,

RESEARCH / INSTRUMENTS AND METHODS FOR BIOMEDICAL APPLICATIONS



DOSIMETRY

Dosimetry

Principal Investigator:
Jorge Sampaio (30)

6 ***Researcher(s):***
Daniel Galaviz (10), José Pires Marques (15), João Gentil (10), Luis Peralta (25), Pamela Teubig (20), Patrícia Gonçalves (10)

9 ***PhD Student(s):***
Carina Coelho (75), Cristiana Rodrigues (50), Dalila Mateus (50), Duarte Guerreiro (65), Joana Antunes (100), Joana Leitão (100), Maria Giorgi (100), Mariana Brás (100), Miguel Molina (50)

9 ***Master Student(s):***
Ana Campos (20), Daniel Salgueiro (100), Edgar Sousa (33), Fábio do Carmo (45), Lia Pereira (75), Maria João Borges (24), Nísia Fernandes (50), Rita Pestana (50), Tomás Almeida (100)

7 ***Undergraduated Student(s) and Trainee(s):***
Afonso Cabrita, Beatriz Fernandes, Bianca Alves, Filipe Ficalho, Hannah Scharff, Juan Rodriguez, Maria Teixeira Rebouta

10 ***External Collaborator(s):***
António Gonçalves, António Paulo, Brígida Ferreira, Carlo Greco, Esmeralda Poli, Federico Herrera, Filipa Mendes, João Seco, Sílvia Viñals, Yolanda Prezado

Total FTE:
13.1 (PhD 1.2)

Articles in international journals:	**1** Article (direct contribution)
Notes:	**2** LIP Students notes
National conferences:	**1** Oral presentation
Nat.& Internat. meetings:	**2** Poster presentations
Advanced Training Events:	**7** Student presentations
Completed theses:	**1** MSc + **1** BSc

Executive summary

The knowledge of the biological efficiency of ionizing radiation in organs and tissues is essential to obtain more precise parameters for radiotherapy planning. This efficiency depends on physical properties, such as linear energy transfer (LET), dose and absorbed dose rate, chemical effects, such as tissue oxygen concentration, the possible presence of radiosensitizing or radioinhibiting chemical agents, and biological factors, such as the type and lineage of irradiated cells, the phase of the cell cycle in which the cells are exposed, and bystander effects, among others.

Therefore, it is important to understand the role of these factors when parameterizing the biological response of organs and tissues to various types of radiation. One would like to obtain a relationship between the physical characteristics of the radiation used and the biological response. This is studied through in vitro and in vivo irradiation experiments of various cell types or with animal models, including xenografts. Knowledge of spatial distributions of LET and dose with high resolution (at the subcellular scale) is particularly important in the case of charged particles, since the biological response to this type of radiation depends strongly on the track-structure of ionizations produced in the tissues.

The goal of the Dosimetry group's activities is to contribute, from a dosimetry point of view, to the analysis and interpretation of pre-clinical and clinical studies in forefront radiotherapy (RT) modalities. The group draws on LIP's core competencies, namely in radiation detector development and Monte Carlo (MC) simulations to leverage two thematic research areas:

1. New detectors and materials for high-resolution dosimetry.
2. New modalities and applications in radiotherapy.

The first area includes the development of new materials and detectors capable of measuring energy depositions at micro and nanometer scales. The second area uses Monte Carlo (MC) simulation tools extensively to study the physical and physicochemical effects of radiation and from these infer biological effects. It also aims to apply faster simulation tools to advance emerging RT modalities.

These two main areas contain research projects that are being developed based on PhD and MSc theses of students at FCUL and IST developing their research under the supervision of LIP researchers. These projects are developed in collaboration with other national (C2TN, IBEB, BioISI, ICNAS) and international research centers (ICPO, DKFZ, CMAM). Particularly relevant is the connection with the groups led by J. Seco (DKFZ) and Y. Prezado (ICPO). The group continues to show the capability to attract students and must do so in a sustainable way in order to consolidate the ongoing research areas and collaborations. The projects have a large contribution from the LIP infrastructures: LOMaC, MW&DL, e-CRLab, and Computing Infrastructures.

LIP's Dosimetry group in Lisbon shares with LIP's OR imaging group in Coimbra the focus on research aiming at further developing radiation therapy treatments, although from different perspectives - from a dosimetry point of view in the case of our group; on the development of real-time or near-real-time beam monitoring techniques in the case of the ORimaging group. The two groups collaborate both within funded research projects (see table below) and in the supervision of PhD and MSc students.

Dosimetry

Overview

The Dosimetry group has started a process of transformation since the prospect of setting up a proton therapy (PT) center in Portugal arose in 2018. The ProtoTera PhD programme was created with the aim of providing specific advanced training and developing research in PT and related fields. The group has benefited from this opportunity and at present has 6 students with ProtoTera grants and 3 with PT-CERN grants. The research areas have thus been developed around their PhD thesis projects. which are being developed in partnership with national and international research centers.

These projects are:

1. New detectors and materials for high-resolution dosimetry

1.1. *SPOF array for high-resolution dosimetry:* Build a detector for radiobiology and quality assurance applications in charged-particle RT. The detector will measure energy deposition on the submillimeter scale using scintillating plastic optical fibers (SPOFs).

1.2. *Development of materials for micro- and nanodosimetry:* Production of a new class of SPOF based on the electrospinning technique and the development of Fluorescent Nuclear Track Detectors (FNTDs) based on corundum crystals.

2. New modalities and applications in radiotherapy.

2.1. *Modeling radiobiological effects of NPs:* Develop and apply computational models based on MC simulations (TOPAS-nBio) to understand the biological effects of radiation on cells internalized with high-Z nanoparticles (NPs). This work is being developed as part of a task in the TPPT project.

2.2. *Advance charged-particle MBRT:* Evaluate the detector performance of several detectors in MBRT with charged particles and develop fast MC simulations for the optimisation of pre-clinical experiments and planning of MBRT treatments from CT images.

2.3. *Advance FLASH-RT:* Model and understand differences between chemical effects in conventional and FLASH-RT via MC simulations and develop and apply a novel strategy for multi-beam FLASH-PT.

2.4. *Effects of proton therapy in neurodegenerative disorders:* Study the effects of proton RT on the self-organization of amyloid structures and the potential impact on the control of neurodegenerative diseases.

Assessment of the past year: objectives vs. achievements

In the following we address each of the projects mentioned in the above thematic lines.

1. New detectors and materials for high-resolution dosimetry.

1.1. *SPOF array for high-resolution dosimetry:* The prototype consists of an array of 64 1-mm thick SPOFs aligned in a frame and connected to a PMT system and the MARTA DAQ board. The assembly of the mechanical parts has been completed and tests were performed that confirm the good alignment of the fibers. Preliminary tests were performed with a low-energy (50 kV) x-ray source showing that there were limitations in the signal processing with this board for high fluxes (>3 kHz). Beam time was also requested through GSI's Bio-PAC programme. The proposal aimed to test the response of our detector to a carbon beam and demonstrate its applicability in charged-particle MBRT. Simulations were carried out that demonstrate the adequacy of our system in resolving the peak and valley structure. However, our proposal was not accepted at this time considering the system is still in early tests.

1.2. *Development of materials for micro- and nanodosimetry:* This project started in March 2022 with the production of the first nanometric sized polystyrene fibers via electrospinning at C2TN. New setups and protocols were tested to produce the fibers in an aligned structure and to increase their thickness in order to allow their manipulation. Methodologies were also tested to characterize those fibers regarding light transmission and porosity. MC simulations were performed to study the structure of energy deposition in the fibers as well as in doped sapphire crystals (FNTDs) for different types of radiation (photons, electrons and protons).

2. New modalities and applications in radiotherapy.

2.1. *Modeling radiobiological effects of NPs*: The algorithm for geometry reconstruction from fluorescent confocal microscopy (CM) images to be imported in the TOPAS program was finalized. The algorithm was applied to Glioblastoma Multiforme (GBM) U87 and U373 cell lines. Simulations mimicking the irradiation performed with a Co-60 source at C2TN were done to compare with the experimental survival curves. The results show a good agreement between our simulations and the survival curves without NPs and with NPs for the three concentrations measured by the C2TN group. At this moment we are waiting for further experimental results to be obtained within the TPPT project by the C2TN group using X-ray and proton beam sources from ICNAS.
A phantom for radiobiology studies was designed and validated with MC simulations. The goal was to produce a phantom that would allow in-depth irradiation of well plates in RT facilities. The primarily intended application is to study the radiosensitization of pancreatic cancer cells with NPs in collaboration with IBEB but it could be used in general in any cell irradiation experiment.

2.2. *Advance charged-particle MBRT:* Simulations were performed with TOPAS to predict output factors (OF) and peak-to-valley dose ratios (PVDR) for the experimental campaign that took place at GSI in May 2022. The PhD student participated in this campaign where the PTW microdiamond detector and Gafchromic films (EBT-3) stacked with Orthochromic films (OC-1) were used to assess the dose profiles in carbon ion MBRT. Correction factors were also derived through MC simulations for the PTW microdiamond detector considering the carbon beam in the GSI setup as well as the IBA RD detector considering the proton beam at the ICPO.

2.3. *Advance FLASH-RT*: Regarding the multi-beam FLASH-PT project, a methodology was tested for the FLASH threshold conditions and implemented in the matRAD toolkit. As proof-of-concept, three different phantom geometries were tested for homogeneity, dose and dose rate metrics, and robustness.

Concerning the study of the differentiating chemical processes of FLASH-RT, a step-by-step MC continuous irradiation model was implemented with the GPU-based MC code gMicroMC. This model accounts for the temporal structure of the beam, its dose rate, and the water's oxygen level.

2.4. *Effects of proton therapy in neurodegenerative disorders*: The first year of this project was dedicated to training the PhD student in MC simulations (TOPAS and TOPAS-nBIO) as well as in biochemistry methods like cell culture, spectroscopy and microscopy techniques. First irradiation experiments of biological samples with a Co-60 source at C2TN were done to study oxidative stress, mitochondrial activity, protein expression and aggregation. TOPAS simulations started to be implemented to benchmark the dosimetry at the C2TN irradiator and to model the interaction of ionizing radiation with amyloids. A review paper on the use of radiation as a potential treatment for amyloidosis was published.

Outreach

The PhD students participated in the ProtoTera Workshop and "Jornadas Doutorais" (FCUL). The group was involved in the organization of the "Particle Therapy Masterclass" in Lisbon.

Lines of work and objectives for next year

In 2023 we intend to continue developing the above mentioned projects. Thus the goals for next year are:

1. New detectors and materials for high-resolution dosimetry.

1.1. *SPOF array for high-resolution dosimetry:* We intend to continue the tests of the prototype with the low energy X-ray source existing at FCUL and MV at Hospital Santa Maria (HSM). There is also the possibility of testing with a clinical proton beam at the HollandPTC within the scope of our task in the ImprovingPT project (CERN/FIS-TEC /0017/2021). Optimization of the operational parameters of the MARTA DAQ will continue. As an alternative option we will test the possibility of using the TRB board that allows for a higher counting rate (30 MHz) although unable to process the signal amplitude.

1.2. *Development of materials for micro- and nanodosimetry*: Fiber production will pursue using an alternative method called melt-electrospinning. The goals are: improve transparency of fibers (currently at 30%) and increase the fiber diameter from a few micrometers to 10ths micrometers to allow an easier mechanical micromanipulation. The inclusion of dopants such as PTP will be decided upon concluding the optimization of these optical and mechanical characteristics. Depending on the acquisition of a platinum crucible is foreseen the production and characterization of FNTDs of corundum crystals. MC simulations will closely follow the laboratory developments.

2. New modalities and applications in radiotherapy.

2.1. *Modeling radiobiological effects of NPs:* Simulate the irradiation conditions for X-ray sources and the ICNAS proton beam to compare with the expected experimental results within the TPPT project. Start implementing the simulation of ROS yields (G-values) in the reconstructed cell geometries (realistic GBM) for the same conditions. A paper on the Co-60 source benchmarking is in preparation to be submitted in 2023.

2.2. *Advance charged-particle MBRT:* The newly released gpu-based code MOQUI will be tested and validated against TOPAS simulations for normal PT and proton MBRT for the ICPO beamline. A MC evaluation of a proton MBRT treatment plan for cardiac radioablation in CT images of an anonymized patient has started and will proceed in 2023.

2.3. *Advance FLASH-RT:* Apply the matRAD toolkit to different treatment sites using images of previously treated patients and compare the results with the conventional RT. Regarding the study of the chemical effects in FLASH-RT, the implemented model will be benchmarked by comparing the G-values yields with the experimental ones obtained for conventional and FLASH-RT.

2.4. *Effects of proton therapy in neurodegenerative disorders:* Irradiation experiments at HSM with MV X-rays and at CMAM, Madrid, with protons. Measurement of dosimetric parameters to characterize the homogeneous irradiation with protons in air for EuB and IMP beam lines at CMAM. Continuation of the TOPAS simulations considering the X-ray and protons irradiation setups.

Outreach

The development of these projects revealed that there are several small groups researching radiobiology in Portugal with little contact between them, although some of them work on very related topics. None of these groups has access to all cellular analysis techniques or to local irradiation facilities, which can be useful for initial beam tests. Therefore, we propose to organize a national workshop in the area of radiobiology and microdosimetry in order to disseminate among the participants the activities in these topics in Portugal, and to make known the equipment and radiation sources available in the various research centers.

It is also foreseen that in 2023 the outputs of a few of the ongoing projects will be presented at European conferences.

Medium-term (3-5 years) prospects

The group's main objective in the coming years is to develop and deepen projects related to instrumentation and MC simulations related to radiobiology and emerging RT modalities with charged particles. We intend that these projects reinforce the collaboration between LIP researchers and researchers in the field of biochemistry, cell biology, and material sciences.

In the next 3-4 years we aim to have our SPOF array dosimeter prototype tested and validated in a real environment. This validation includes having a second plane of fibers allowing 2D mapping of the dose distribution, using thinner fibers to improve the spatial resolution, and the development of a protocol to grow cell cultures on the surface of the fibers. We will also proceed to test the capabilities of the detector in PT QA and MBRT dosimetry.

The development of new detectors capable of breaking the limits of spatial resolution in dosimetry is also a line that we want to continue to explore. The activities related to the production of FNTDs crystals and small diameter scintillating fibers are to proceed in the medium-term.

We also plan to improve the group's competencies in simulations related to nanoscale dosimetry and radiochemical effects using TOPAS-nBIO as well as developing faster simulations with the GPU-based codes like gMicroMC and MOQUI. The group should also deepen its knowledge in the mathematical models of the biological effects of radiation and apply these skills in emerging modalities of charged-particle RT.

SWOT Analysis

Strengths

The group has long-term competencies in MC simulations and in detectors based in scintillating materials. It has a great ability to attract students. Aggregates competences from several LIP infrastructures in common projects. Started to establish collaborations with researchers in biochemistry, cell biology, and material sciences (BioISI and C2TN).

Weaknesses

The group is still developing skills beyond physics, particularly with regard to radiobiological models. Needs to consolidate collaborations and activities directly linked to pre-clinical and clinical research. The number of FTE researchers is small in relation to the number of projects being developed. It has no programmed funding allocated for the development of most projects and to support the activities of students and researchers.

Opportunities

The installation of more than 10 new PT centers in Spain could be an opportunity for the group to promote further collaborations with the neighboring country. In this respect the work with CMAM is very important, but other potential collaborations should be identified and promoted. The collaboration with J. Seco (DKFZ) and Y. Prezado (ICPO) are important to leverage these collaborations.

Threats

The plan to install a PT center in Portugal has apparently been put on hold, which could threaten the future support of the group's activities. The lack of medium-term funding constrains the scale of collaborations with other groups and limits the support to the ongoing PhD projects. The sustainability of supervising students also depends on the number of FTE researchers available in the group. Of particular concern is the possibility that the contract of one of the group's researchers will terminate at the end of the year.

Dosimetry

Publications

1 Article in international journal (with direct contribution from team)

- *"Radiation as a Tool against Neurodegeneration-A Potential Treatment for Amyloidosis in the Central Nervous System ",* Coelho CM, Pereira L, Teubig P, Santos P, Mendes F, Viñals S, Galaviz D, Herrera F

2 LIP Students Notes

- *"First Measurements with a Scintillating Fiber Microdosimeter"*, Beatriz Fernandes, LIP-STUDENTS-22-08
- *"Performance of microdosimetric detectors using Monte-Carlo"*, Filipe Ficalho, LIP-STUDENTS-22-20

Presentations

2 Poster presentations in international conferences

- Joana Leitão: *"Proton Multi-Beam FLASH Radiotherapy: Combining FLASH and IMPT"*, 2022-11-30, Flash Radiotherapy and Particle Therapy 2022, Barcelona
- Miguel Molina: *"Monte Carlo Modeling of Inter-Track Radical Reactions for FLASH"*, 2022-11-30, Flash Radiotherapy and Particle Therapy 2022, Barcelona

1 Presentation(s) in national conference(s)

- J. P. Marques: *"RADIAT ION EMISSION IN RADIONUCLIDES WITH BIOMEDICAL INTEREST"*, 2022-09-09, "Física 2022 - 23ª Conferência Nacional de Física e 32º Encontro Ibérico para o Ensino da Física" of the Portuguese Physical Society, Porto, September 7-10, 2022., Porto, Portugal

10 Student presentations in advanced training events

- Joana Antunes: *"Modeling the radiobiological effects of gold nanoparticles in proton therapy of glioblastoma"*, 2022-06-06, 7th IDPASC/LIP PhD Students Workshop, Coimbra
- Cristiana Rodrigues: *"Development of microdosimetric detectors for radiobiology in hadron therapy facilities"*, 2022-07-06, 7th IDPASC/LIP PhD Students Workshop, Coimbra
- Duarte Guerreiro: *"Scintillation dosimetry with plastic optical fibres"*, 2022-07-07, 7th IDPASC/LIP PhD Students Workshop, Coimbra
- Maria Giorgi: *"Dosimetry evaluation to advance charged particle minibeam radiotherapy "*, 2022-11-28, 1st Prototera PhD Students Workshop, Coimbra
- Mariana Brás: *"Dosimetry using prompt gamma-x spectroscopy"*, 2022-11-28, 1st Prototera PhD students Workshop, Coimbra
- Joana Leitão: *"Proton Multi-Beam FLASH Radiotherapy: Combining FLASH and IMPT"*, 2022-11-28, 1st Prototera PhD students Workshop, Coimbra
- Miguel Molina: *"Monte Carlo Modeling of Inter-Track Radical Reactions for FLASH Radiotherapy"*, 2022-11-28, 1st Prototera PhD students Workshop, Coimbra
- Joana Antunes: *"Modeling the radiobiological effects of gold nanoparticles"*, 2022-11-29, 1st Prototera PhD Students Workshop, Coimbra
- Cristiana Rodrigues: *"Development of microdosimetric detectors for radiobiology in hadron therapy facilities "*, 2022-11-29, 1st Prototera PhD Students Workshop, Coimbra
- Duarte Guerreiro: *"New radiobiology detector using scintillating arrays"*, 2022-11-29, 1st Prototera PhD Students Workshop, Coimbra

2 Poster presentations in national or international meetings

- Joana Antunes: *"Modeling the radiobiological effects of gold nanoparticles in proton therapy of glioblastoma"*, 2022-07-08, Jornadas LIP 2022, Coimbra
- D.R.Guerreiro, B.C.Alves, M.Giorgi, J.M.Sampaio, L.Peralta, J.Gentil: *"Study of the viability of a scintillation detector for minibeams dosimetry"*, 2022-07-08, Jornadas LIP 2022, Coimbra

1 Seminar

- Patrícia Gonçalves: *"Protons against cancer: using charged particles in radiotherapy"*, 2022-02-17, Jornadas de Doutoramento do Departamento de Física da Faculdade de Ciências da Universidade de Lisboa, FCUL, Lisboa

Theses

9 PhD

- Joana Leitão: *"Developing Multi-Beam FLASH with Proton Beams"*, 2021-10-04 / 2025-10-03, (ongoing), IST, Supervisor(s): Patrícia Gonçalves, João Seco
- Duarte Guerreiro: *"Scintillating array for real-time high-resolution ion therapy dosimetry"*, 2020-09-01 , (ongoing), FCUL, Supervisor(s): Jorge Sampaio, Luis Peralta
- Carina Coelho: *"The effects of proton therapy on protein self-organization: potential benefits for neurodegenerative disorders"*, 2021-10-01 , (ongoing), FCUL, Supervisor(s): Daniel Galaviz
- Dalila Mateus: *"Estudos dosimétricos para SBRT/SRT de pequenas lesões do Cérebro"*, 2019-03-07 , (ongoing), FCUL, Supervisor(s): Luis Peralta
- Miguel Molina: *"Evaluating the Effectiveness of Mini-Beam Radiation in Cancer Therapy"*, 2021-03-01, (ongoing), IST, Supervisor(s): Patrícia Gonçalves, João Seco
- Joana Antunes: *"Modeling the radiobiological effects of gold nanoparticles in proton therapy of glioblastomas"*, 2021-02-01 , (ongoing), FCUL, Supervisor(s): Jorge Sampaio
- Maria Giorgi: *"Development of a dosimetry protocol for proton minibeam radiotherapy"*, 2021-10-01 , (ongoing), FCUL, Supervisor(s): Jorge Sampaio
- Mariana Brás: *"Adaptive dose reconstruction with online in-vivo range verification in particle therapy"*, 2021-09-13 , (ongoing), IST, Supervisor(s): Patrícia Gonçalves, João Seco
- Cristiana Rodrigues: *"Development of microdosimetric detectors for radiobiology in hadron therapy facilities"*, 2022-03-02 , (ongoing), FCUL, Supervisor(s): João Gentil, Luis Peralta

8 Master + 1 Bachelor

- Nísia Fernandes: *"Estudo da radiossensibilização de células tumorais do pâncreas com nanopartículas"*, 2020-11-05 / 2022-01-31, (finished), FCUL, Supervisor(s): Jorge Sampaio

- Fábio do Carmo: *"Cálculo de espetro de emissão de Auger para simulações de radioterapia sensibilizada com nanopartículas de ouro "*, 2022-09-19 / 2023-12-31, (ongoing), FCUL, Supervisor(s): Jorge Sampaio, José Pires Marques
- Edgar Sousa: *"Dosimetria com filme aplicada aos feixes de eletrões com taxa de dose ultra-alta (Flash) "*, 2022-09-01 / 2023-12-31, (ongoing), FCUL, Supervisor(s): Luis Peralta
- Maria João Borges: *"Beam tests of a scintillation array detector for high-resolution dosimetry"*, 2022-10-03 / 2023-12-31, (ongoing), FCUL, Supervisor(s): Jorge Sampaio, João Gentil
- Lia Pereira: *"Modelling protein amyloid structures and observing the effects of radiation using the GEANT4-DNA toolkit"*, 2021-10-04 , (ongoing), FCUL, Supervisor(s): Daniel Galaviz
- Ana Campos: *"Estudo da dispersão de partículas alfa em filmes finos"*, 2018-07-01 , (ongoing), FCUL, Supervisor(s): Luis Peralta
- Tomás Almeida: *"Design of a phantom for radiobiology studies"*, 2021-12-01 , (ongoing), FCUL, Supervisor(s): Jorge Sampaio
- Daniel Salgueiro: *"Design of a fiber-phantom detector for quality assurance in PT"*, 2021-09-13 , (ongoing), FCUL, Supervisor(s): Jorge Sampaio, João Gentil
- Bianca Alves: *"Dosimetria com Mini-Feixes utilizando um detetor constituído por um array de fibras óticas de cintilação"*, (finished on 2022-06-30), ISEL - Supervisor: Jorge Sampaio and Pedro Martins Ferreira

[Radiation environment studies and applications for space missions]

SpaceRad
i-Astro

RESEARCH / RADIATION ENVIRONMENT STUDIES AND APPLICATIONS FOR SPACE MISSIONS

SPACERAD

Space Radiation Environment and Effects

Principal Investigator:
Patrícia Gonçalves (40)

3 ***Researcher(s):***
Bernardo Tomé (10), Luisa Arruda (75), Pedro Assis (18)

4 ***Master Student(s):***
António Pessanha Gomes (100), Francisca Santos (75), Igor Miguel Gago (100), Miguel Lopes (17)

2 ***Undergraduated Student(s) and Trainee(s):***
Luis Cabral, Nyvenn Castro

2 ***External collaborator(s):***
Carlota Cardoso, Marco Alves Pinto

Total FTE:
4.3 (PhD 1.4)

Articles in international journals:	**4** Direct contribution
Notes:	**1** Internal note **1** Collaboration note
International conferences:	**1** Oral presentation
National conferences:	**1** Oral presentation
Nat.& Internat. meetings:	**2** Oral presentations **1** Poster
Collaboration meetings:	**2** Oral presentations
Advanced Training Events:	**3** Oral presentations **1** Student presentation
Seminars:	**10** Outreach seminars
Completed theses:	**1** MSc

Executive summary

The SpaceRad group, established 19 years ago, covers the area of research and development focused on the study of the space radiation environment and of its effects. The work developed is in line with the ESA roadmap for the area of "Space Radiation environment and Effects" and the competences developed in this field encompass all the technologies identified by ESA on its harmonised roadmap. LIP is a national academic and R&D reference in these areas, which are identified as:

- Environment analysis & Modelling: improve the quality of radiation belt models, radiation environments modelling in specific locations, study and describe radiation environments due to solar emissions and galactic cosmic radiation.
- Radiation Effects Analysis tools: develop tools to enable precise and user-friendly radiation shielding and effects calculation, including for single event effects (SEE).
- Radiation measurement: Radiation measurement technologies.
- Radiation Hardness Assurance: Investigation of the effects of radiation on new types of electronic components and in specific environments (total ionizing dose - TID), investigation of the effects of radiation on new types of electronic components and in specific environments (single event effects - SEE), development of testing facilities, development and exploration of in-flight experiments and tests, methodologies for radiation hardness assurance and effects on biological systems/manned flights.

In its activities, mostly developed under contracts with ESA, LIP has been working with different European entities, from academia and from the industry, such as the Paul Scherrer Institute in Switzerland, and EFACEC S.A., a Portuguese industrial partner, among others.

Currently SpaceRad leads a project for the support of the quality and calibration of the data of two radiation monitors flown in two ESA Planetary Missions: the BERM instrument on board of the BepiColombo mission to Mercury and RADEM on board of the future JUICE mission to the Jovian System to be launched in 2023. These monitors will provide unique data sets and consequently will be used as windows to the Heliosphere for multi-observation of Solar Particle Events and for energetic particle propagation studies.

SpaceRad is also preparing for future Mars and Lunar missions, for which it can contribute with the predictions of dMEREM, the GEANT4 detailed Mars Energetic Radiation Environment Model, which is foreseen to be adapted to the description of the Lunar and Cislunar radiation environments.

In the development of instruments and methods, a preliminary study of a customizable low cost radiation monitor, that can be used both in small satelites and on the Moon will be started in 2023 and the development of PlanetRAD Virtual lab, a GEANT4-Python tool for the demonstration of different planetary radiation environments, will be continued.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Patrícia Gonçalves	ESA	300.000 €	2014-02-18 to 2022-03-31	ESA: 1-7560/13/NL/HB / RADEM proto-flight model (for the JUICE mission to the Jupiter icy moons)
Patrícia Gonçalves	ESA	75.000 €	2022-04-01 to 2025-03-31	ESA: 4000137865/22/ES/JD / BARD - Expert Suport to BERM (aboard BepiColombo) & RADEM (aboard JUICE) units

SpaceRad

Overview

Context

SpaceRad Group activities cover the range of research & development topics listed below:

- Study of the radiation environment, in orbit, interplanetary space and surface layers of the planets of the Solar System, participating both in on-going and future exploration missions through the exploitation of scientific data and development of new technologies and dedicated sensors.
- Evaluate the effects of space radiation on crews, study dosimetry systems for manned space missions. Study and design shielding solutions for spacecraft and shelters for radiation protection of astronauts and electronic systems in space.
- Study the effect of ionizing radiation on cell structure as one of the main factors limiting the survival of life forms in potential astrobiological habitats. The modelling and data analysis of radiation environments are fundamental to predict the survival possibilities of life forms in different planetary environments in the Solar System.
- Extreme solar events, such as super storms, which can seriously affect modern technological infrastructure (power distribution networks, telecommunications), given the dependence of this infrastructure on applications located in orbit (satellites). The knowledge and study of space weather, and especially the enhancement of the predictive capability of extreme events is fundamental to protect the terrestrial infrastructure, along with the development of mitigation strategies of this type of occurrence.
- Assess the radiation effects on EEE components and satellite systems and in specific space missions, in particular using Commercial Off-The-Shelf (COTS) components, both through testing and modeling of radiation effects.
- Outreach activities.

Ongoing activities

The current group activities are centred in the analysis of the data from two radiation monitors capable of measuring charged particle spectra in the inner and outer solar system: the BERM detector aboard the BepiColombo mission to Mercury and the RADEM, the Radiation Hard electron Monitor for the ESA JUICE mission to the Jovian system to be launched in April 2023. The group continues to explore the potential of the Geant4 based dMEREM, the detailed Martian Radiation Environment Model developed at LIP for ESA, in the preparation of future crewed missions to Mars and the Moon and on the interpretation of its results in terms of implications for Human Space Flight and for astrobiology studies.

The Group

The SpaceRad group coordinator, Patrícia Gonçalves, is an associated professor at Instituto Superior Técnico of the University of Lisbon and therefore most students developing their theses with the group are coming from the IST MSc in Physics Engineering (MEFT). The supervision of theses is usually supported by Marco Pinto (as external collaborator in 2022 and 2023, during his research fellowship with ESA) and by Luisa Arruda. All theses in progress are MSc theses.

Bernardo Tomé and Pedro Assis, with smaller participations in the SpaceRad group, give support to the simulation activities and to the instrument development and test activities, respectively.

Assessment of the past year: objectives vs. achievements

Follow up from previous contracts and publications:

- The RADEM contract finished in 2022 and the radiation monitor was integrated in the ESA JUICE spacecraft, which will be lauched from Kourou in an Ariadne 5 rocket in April 2023. Patrícia Gonçalves was designated team-leader of the RADEM instrument, together with Wojtek Hadjas from PSI.
- The BERM calibration and in-flight data analysis was addressed, including a cross calibration with the SIXS instrument also onboard of BepiColombo. This work was done in collaboration with Marco Pinto and in the framework of the MsC thesis of Carlota Cardoso, where she applied a Bow-Tie Analysis to the BERM Earth flyby data, to extract proton and electron spectra from detector counts in the proton and electron channels.
- A test of a Bow-Tie analysis was tested as an unfolding method for the MFS measured fluxes of the MFS data was started.
- A paper on the pioneer study of the effects of radiation in GaN electronics aboard the CTTB (AlphaSAT) was successfully published in Nature Scientific Reports. This study, where the performance of the GaN components was analysed as a function of the Total Ionizing Dose measured by the GaN board RADFET, was done in collaboration with Instituto de Telecomunicações at Universidade de Aveiro, responsible for the GaN experiment aboard the CTTB.
- The activities concerning the exploration of dMEREM, the GEANT4 based detailed Mars Energetic Radiation Environment Model continued and The validation of the Model with data from the RAD detector on the Martian surface was published.
- The paper “Source of very energetic oxygen located in Jupiter's inner radiation belts”, resulting from the collaboration with Elias Roussos from the Max Planck institute for Solar System Research, which started within the JUICE science working team in preparation of future RADEM data analysis, was published.

Proposals

Two proposals were prepared for 2022 calls:

- The contract with ESA "BARD - Expert support to BERM (BepiColombo Environment Radiation Monitor) & RADEM units on board BepiColombo and JUICE spacecraft", with LIP as prime contractor and SE2S (a Paul Scherrer Institute Spinoff company) from Switzerland as partner, started on April 2022. The contract has a duration of three years, renewable for the duration of the missions.
- The ESA Tender Action 1-10748 - Galileo Second Generation Satellites Batch 1 Radiation Monitoring Units (RMU) Procurement - Prepared jointly with EFACEC, S.A. and the remaining RADEM contract partners, which was not selected due to unacceptance by ESA of adjustable firm prices as proposed by EFACEC, S.A, given the present volatility of material prices.

Theses

During 2022: Carlota Cardoso successfully presented her Master thesis at IST; Francisca Santos started her Master thesis on the launching of RADEM; António Gomes started his master thesis on BERM flight data analysis (see details in the list of theses at the end of the group report)

Internships

The SpaceRad group hosted the following Internships during 2022:

- SEP events on the surface of Mars - IST MsC Engineering Physics students : Nyvenn Castro and Luís Cabral - July 2022
- Analysis of the, Mars, Moon, Interplanetary using PlanetRAD - IST Minor on Sciences & Technologies students - July 2022
- Mário Amaro, an Aerospatial Engineering student at IST, finished his internship on the characterisation of the radiation environment at different Earth orbits: LEO, MEO and GEO.

Software Tools

The Virtual Radiation physics Laboratory

The Virtual Radiation Physics Laboratory (VRLab) is a set of GEANT4 Applications interfaced via Python with a Graphical User Interface, allowing the users to choose the conditions of the experiments. The Interface also allows to display graphic distributions with the results of each virtual experiment. In 2022, a preliminary module for the simulation of the Martian, Lunar an Earth atmospheres - PlanetRAD - was developed by the group to serve as a laboratory setup for students fo the Space Physics course of the IST minor on Space Science and Technology.

Lines of work and objectives for next year

Starting from 2023 the SpaceRad group activities are summarized into three lines, which are listed below.

Radiation Monitors as windows to the Heliosphere

The contract for the development of the RADEM flight model closed in 2022. The SpaceRad group continues to participate in the JUICE Mission Science Working Group and also in the framework of the BARD contract. The focus of JUICE is to characterise the conditions that may have led to the emergence of habitable environments among the Jovian icy satellites, with special emphasis on the three ocean-bearing worlds, Ganymede, Europa, and Calisto. JUICE will be launched in April 2023, will have 3 Earth flybys between 2024 to 2029, a Venus flyby in 2025, and will arrive on the Jovian system in 2031, with end of mission foreseen to 2035. The roup is collaborating with scientists from other JUICE instruments to prepare the JUICE charged particle data analysis, both for the Jovian phase and the cruise phase, and also for Earth flybys.

The BARD contract is also dedicated to support to the BERM BepiColombo mission instrument. BepiColombo was launched in October 2018 and it included Earth flyby in April 2020, a Venus flybys in 2020 and 2021, which will be followed by six Mercury flybys between 2021 and 2025. BepiColombo will enter Mercury orbit in December 2025, providing a unique data set of charged particle data.

In 2023 the SpaceRad group will continue to participate in the scientific teams both of the BepiColombo and of the JUICE missions and explore RADEM and BERM data collected during their cruise phases. Simultaneously, several tasks shall be performed during 2023 in the framework of the BARD contract, such as the production of the BERM calibration software and the production of BERM data quick analysis tools, the commissioning of RADEM and the analysis of its first in-flight data.

Planetary radiation environments: Human Space Flight and Astrobiology

The validation of dMEREM, the GEANT4 based Mars Energetic Radiation Environment Model, with data collected on the Martian surface was published in 2022. The model was shown to provide a very good description of the RAD Curiosity detector proton flux measurements on the Martian surface. It will be used for predicting expected fluxes of other particle and nuclear species, for different Martian surface locations, inside the Martian atmosphere or underground.

In 2023 the activities concerning the exploration of dMEREM will continue with the study of the underground radiation environment to predict the possible existence of conditions for simple life forms and with studies predicting the effect of the energetic particle radiation in crewed missions to Mars.

In particular, the study of Mars subsurface radiation environment, aiming at providing answers to the possibility of microscopic life survivability under such conditions can be a direct application of the detailed Martian Environment Model, if complemented with data from experiments with microbiological species when exposed to different radiation fields corresponding to varying radiation of low and high LET radiation, and using shielding materials matching a set of chosen Martian soil composition scenarios. In this field dMEREM is being upgraded to enable the prediction of biological effects due to the Martian radiation environment at locations on the surface and subsurface of Mars.

Instruments and methods: from Particle and Nuclear Physics to Space and Health Applications

The SpaceRad LIP research group will continue to seek opportunities for collaboration with the industry and with other R&D institutions in the development of new instruments and methods with applications to space and health. Some of the foreseen activities for 2023 consist of a preliminary study for a customizable Low Cost Radiation Monitor that can not only be used in small satellite missions, but that can also be deployed at low cost in planetary environments, such as in the case of the Moon. The development and improvement of the PlanetRAD framework will be continued.

Medium-term (3-5 years) prospects

In the three lines of work identified above, the prospects for the next 3 to 5 years are listed below. In all lines of work, the SpaceRad group will seek to establish and reinforce international collaborations and will explore synergies and interdisciplinary collaborations with other LIP research groups, with groups working on space science and technology at the Lisbon University and also with the space sector industry.

Radiation Monitors as windows to the Heliosphere

The JUICE cruise phase will start in 2023 after detector commissioning, and during that phase the mission will perform three Earth flybys and one Venus flyby, before reaching the Jovian system in July 2031. JUICE will then spend over three years exploring the Jovian system and its icy moons in particular: Ganymede, Calisto and Europa. The BepiColombo mission will have its insertion in orbit of Mercury in 2025, but it has already provided several opportunities to obtain and analyse charged particle data with BERM, during the cruise phase, including the 2021 Earth Flyby and the 2022 Mercury flybys.

Therefore, from April 2023 BERM and RADEM will be flying simultaneously at different points of the Heliosphere, providing the SpaceRad group an unique opportunity to collect and analyse Galactic Cosmic Rays and Solar Particle Events during the Solar Maximum period, which is foreseen to be reached in 2023-2024 and to last until 2026.

Both data sets, BERM´s and RADEM´s, will give valuable insights into the Heliosphere, providing information at different points. They will also contribute to advancing the state of the art knowledge on the magnetospheres of the planets and on their interactions with the Heliosphere, which affect the propagation of Solar Energetic Particle Events, relevant for space weather and for the preparation of future human space flight. Additionally, in the case of JUICE, new insights on Europa, Ganymede and Calisto are expected. The study of Ganymede´s particle radiation environment, with its own magnetosphere, is an important subject on its own. In particular, RADEM´s Directional Detector was developed also with the purpose of measuring electron directional fluxes in Ganymede´s magnetosphere, following Galileo mission's measurements that showed a variation of electron flux directions and intensities during Galileo's Ganymede flyby. The preparation of the RADEM Jovian phase data analyses will start at medium term, with the supervision of students and with increased collaboration with the teams of the JUICE mission scientific instruments.

Planetary radiation environments: Human Space Flight and Astrobiology

Continue the line of work on modelling of radiation environments at different locations in the solar system, such as Mars and the Moon, and on the application of the developed models to future robotic and human-crewed missions.

For human space flight, the synergies with the LIP's Dosimetry group are fundamental for the adaptation of dMEREM to the Lunar radiation environment. The strategy used in the development of the dMEREM, is thus the basis for the foreseen development of a Lunar and CisLunar Radiation Environment model, whose preliminary studies and data assessment are ongoing and which will be the subject of a future proposal for European funding. The Lunar and Cislunar Radiation environment model is foreseen to be integrated with dMEREM, in a common application to be made available to the community. In these developments the collaboration with the international community will be essential, and may take the form of common applications to future European funding calls.

Instruments and methods: from Particle and Nuclear Physics to Space and Health Applications

If the preliminary concept of a customizable low cost radiation monitor is found to be promising, the development of an instrument prototype is a possible line of work in the medium term. Opportunities for collaboration within LIP, IST and with our industrial partners in the field of EEE component testing with radiation sources and particle beams and radiation hardness assurance will also be sought.

SWOT Analysis

Strengths and Opportunities

- Expertise in GEANT4 for space applications is well developed and LIP is the only Portuguese R&D institution with background in the area of space radiation environment and effects in ESA contracts.
- It is an applied area, not a fundamental science activity, and it can be seen as an interface area to several fields with a high level of interdisciplinarity. This is an advantage for the collaboration with industry, merging the gap between academia and companies, and in the attraction of engineering students.
- The group holds a very solid physics background with senior members coming from different research areas and with a wide experience in participating in international scientific collaborations.
- Senior members involved with academia, which facilitates the attraction of new students for the group, providing a strong training platform.
- Possibility of Participating in consortia for EU calls and other international funding programmes; Participation in scientific consortia or teams for future space missions to enhance the scientific component of the activity; Collaboration with other LIP groups in common or in complementary subjects.
- Connection and networking with Portuguese community in Space for science and exploration.
- Creation of a Space Science and Technologies minor in Instituto Superior Técnico
- Ongoing research receiving wide (both popular and scientific) interest.
- Future collaboration with coleagues with machine learning expertise in satellite data exploitation.

Weaknesses and Threats

- In terms of funding the group heavily depends on contracts with ESA, with a typical duration of one to 3 years. There can be several of these contracts overlapping in time, which demands too much manpower, and results in possible convergent delivery dates, making it difficult to comply with contract planning. There can be periods of time between contracts in which the baseline and more scientific activities may lack funding.
- In addition, national project calls have been unpredictable in what concerns their rules, publication of results and replies to review requests. Evaluation panels are not from this area and hardly see the real potential of the proposals.
- Students' learning curve has a mild slope and it is therefore difficult to articulate with the average duration of the contracts. On the other hand, there are many attractive opportunities for trained students in industry, in Portugal and abroad, while career prospects for Post-docs and young researchers are difficult.
- Competition with international industry for skilled PhD students and post-doc researchers is not favourable to LIP because of job insecurity and pay level.
- Constant networking effort and attention to ESA intended and published invitation to tender calls is required, as well as to EU opportunities. There is also the risk of starting to plan for this activity as a service oriented activity only, when the scientific potential can be exploited. Extra funding needs to be obtained to cover the scientific topics, properly and coherently.
- Low number of senior researchers in the group.
- Permanent positions would offer a more structured career development path for some senior members.
- The group coordinator is involved in LIP efforts to promote charged particle therapy in Portugal and in LIP management, with a deficit of availability for the group's projects.

SpaceRad

Publications

4 Articles in international journals (with direct contribution from team)

- *"A source of very energetic oxygen located in Jupiter's inner radiation belts"*, Elias Roussos,Christina Cohen, Peter Kollmann, Marco Pinto, Norbert Krupp, Patricia Gonçalves, Konstantinos Dialynas, Space Advances, Vol 8, Issue 2
- *"Validation of dMEREM, the Detailed Mars Energetic Radiation Environment Model, with RAD Data from the Surface of Mars"*, Patricia Goncalves, Luisa Arruda, Marco Pinto, Front. Astron. Space Sci. 9 (2022) 833144
- *"Pioneering evaluation of GaN transistors in geostationary satellites"*, Hugo Mostardinha, Diogo Matos, Nuno Borges Carvalho, Jorge Sampaio, Marco Pinto, Patricia Gonçalves, Tiago Sousa, Paul Kurpas, Joachim Wuerfl, Andrew Barnes, François Garat & Christian Poivey , Sci Rep 12, 12886 (2022)
- *"The BepiColombo Environment Radiation Monitor, BERM"*, Marco Pinto, Beatriz Sanchez-Cano, Richard Moissl, Johannes Benkhoff, Carlota Cardoso, Patrícia Gonçalves, Pedro Assis, Rami Vainio, Philipp Oleynik, Arto Lehtolainen, Manuel Grande & Arlindo Marques , Space Sci. Rev. 218 (2022) 54

1 Internal Note(s)

- *"The Ionising Radiation Environment in the Solar System "*, Patrícia Gonçalves, Sintese da Lição para prestação de Provas de Agregação / Habilitation Scientific Lesson at IST

1 Collaboration note(s) with internal referee

- *"Industrial Data Calibration Report"*, Carlota Cardoso, Patrícia Gonçalves, BARD-LIP-TR0001 Analysis-Industrial-BERM-Data

Presentations

1 Oral presentation(s) in international conference(s)

- Cardoso, C., Pinto, M., Gonçalves, P., Sanchez-Cano, B., Moissl, R., Vainio, R., Oleynik, P., Benkhoff, J., Assis, P., Lehtolainen, A., Grande, M., Murakami, G., Hajdas, W., and Marques, A: *"First Analysis of Solar Energetic Particles with the BepiColombo Radiation Monitor (BERM)"*, 2022-09-21, Europlanet Science Congress 2022: Europlanet Science Congress 2022, Granada

2 Oral presentations in national or international meetings

- Carlota Cardoso, Patrícia Gonçalves: *"Space Radiation Environment & Effects"*, 2022-07-09, Jornadas LIP 2022, Coimbra
- Astro-NFIST: astronomy section of the Physics Students Group at Instituto Superior Técnico: *"Women in Astroparticle Physics"*, 2022-12-13, Round table on Women in Physics and Astroparticle Physics, Anfiteatro Abreu Faro, Complexo Interdisciplinar, Instituto Superior Técnico, Alameda

1 Presentation(s) in national conference(s)

- Patrícia Gonçalves: *"From Particle Physics to Health & to Space"*, 2022-05-16, Encontro Ciência 2022, Centro de Congressos, Lisboa

1 Poster presentation(s) in national conference(s)

- Francisca Santos: *"RADEM JUICE Spectrometers Data Analysis and Calibration Review preparation"*, 2022-07-09, Jornadas LIP 2022, Coimbra

3 Oral presentations in advanced training events

- Patrícia Gonçalves: *"Space radiation and particle therapy"*, 2022-05-12, 7th Mini-school on Particle and Astroparticle Physics, online
- Luisa Arruda: *"Radiation environment in space"*, 2022-07-15, LIP Internship Program 2022, LIP
- Patrícia Gonçalves: *"The Ionising Radiation Environment in Mars"*, 2022-08-31, Mars Science and Engineering Program, online

1 Student presentation(s) in advanced training event(s)

- Nyvenn Castro, Luis Cabral: *"SEP events on the surface of Mars"*, 2022-07-15, Apresentação final de estágio LIP- TNFP, LIP

10 Outreach seminars

- Luisa Arruda: *"Espaço: Para o infinito e mais além mas em segurança!"*, 2022-10-04, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Secundária António Damásio, Lisboa
- Pedro Abreu, Patricia Gonçalves, Joana Gonçalves de Sá, Elise Le Boulicaut, Ricardo Gonçalo, Tracey Berry, Steven Goldfarb: *"Universal Science: Curiosity, Diversity, Discovery"*, 2022-10-14, Reunião da colaboração ATLAS do LHC do CERN - Sessão pública, Reitoria da ULisboa
- Luísa Arruda: *"Para o Infinito e mais além mas em segurança!"*, 2022-10-19, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Básica Vasco Santana, Ramada, Odivelas
- Luisa Arruda: *"Para o Infinito e mais além mas em Segurança!"*, 2022-10-26, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Básica Elias Garcia, Sobreda, Almada - 7º ano
- Luisa Arruda: *"Para o Infinito e mais Além mas em Segurança!"*, 2022-11-08, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Secundária Marquês de Pombal, Lisboa - 10º ano
- Luisa Arruda: *"Para o Infinito e mais além mas em Segurança!"*, 2022-11-11, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Secundária Dr. António Carvalho Figueiredo, Loures - 7º ano
- Luisa Arruda: *"PARA O INFINITO E MAIS ALÉM MAS EM SEGURANÇA!"*, 2022-11-15, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Básica e Secundária Amélia Rey Colaço, Linda-a-Velha, Oeiras - 8º ano
- Luisa Arruda: *"PARA O INFINITO E MAIS ALÉM MAS EM SEGURANÇA! - LIP"*, 2022-11-25, O Espaço vai à escola 2022: O Espaço vai à Escola- ESERO 2022, Escola Básica Vasco Santana, Ramada, Odivelas - 7º ano

- Luisa Arruda: *"Para o Infinito e Mais além mas em Segurança!"*, 2022-11-29, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Básica Vasco Santana, Ramada, Odivelas - 9º ano
- Luisa Arruda: *"Para o Infinito e mais além mas em Segurança!"*, 2022-12-07, O Espaço vai à escola 2022: O Espaço vai à Escola-ESERO 2022, Escola Secundária Stuart Carvalhais, Massamá, Sintra - 10º ano

Theses

5 Master

- Carlota Cardoso: *"Flight data analysis of the BERM radiation monitor aboard the BepiColombo mission to Mercury"*, 2021-06-09 / 2022-07-05, (finished), IST, Supervisor(s): Patrícia Gonçalves, Marco Alves Pinto
- Miguel Lopes: *"Integration of the HiRezBrainPET with a clinical PET/CT system – Image performance evaluation of a prototype for next-generation brain tomography "*, 2022-10-31 / 2023-12-31, (ongoing), IST, Supervisor(s): Patrícia Gonçalves,
- Igor Miguel Gago: *"Life prospection on Mars - Studing the Martian Subsurface Radiation Environment"*, 2021-11-11 , (ongoing), IST, Supervisor(s): Patrícia Gonçalves, Luisa Arruda
- Francisca Santos: *"Launching the Radiation Hard Electron Monitor aboard the ESA JUICE mission"*, 2022-03-15 , (ongoing), IST, Supervisor(s): Patrícia Gonçalves, Marco Alves Pinto
- António Pessanha Gomes: *" Flight data analysis of the BERM radiation monitor aboard the BepiColombo mission to Mercury"*, 2022-12-01 , (ongoing), IST, Supervisor(s): Patrícia Gonçalves, Marco Alves Pinto

I-ASTRO

Space Instrumentation for Astrophysics

Principal Investigator:
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6 ***Researcher(s):***
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Total FTE:
7.4 (PhD 2.8)

Articles in international journals:	**1** Direct contribution
International conferences:	**3** Oral presentations **1** Poster **1** Proceeding
Nat.& Internat. meetings:	**1** Oral presentation
Seminars:	**1** Outreach seminar
Completed theses:	**2** MScs

Executive summary

LIP's Space Instrumentation for Astrophysics Group (i-Astro) develops its research activities in the domain of high-energy astrophysics and Terrestrial Gamma-ray Flashes (TGFs) science and effects, in the framework of several mission proposals to ESA, NASA and EU. These are long term projects whose technology and science case are validated and improved by previous small size space and balloon borne missions in the framework of ESA programmes such as: BEXUS, Euro Material Ageing onboard the International Space Station (ISS) and the Space Rider.

Our group is part of the High Energy Astrophysics Domain (AHEAD2020) EU project consortium as well as of NASA All-sky Medium Energy Gamma-ray Observatory (AMEGO) mission proposal consortium. Furthermore we are leading two small-size ESA funded projects: Gamma-ray Laue Optics and Solid State detectors experiment (GLOSS) onboard the ISS; and TGF and High-energy astrophysics Observatory for gamma-Rays (THOR) on board the Space Rider. In these projects our group is developing gamma-ray and particle sensor systems based in CdTe, CsI, Si for high-energy astrophysics, including front and back-end electronics.

The AHEAD2020 EU funded project started in March 2020. Our group is a participant of Work Package 11 (WP11), "Space Experiments for HE Astrophysics & Multi-messenger Astronomy" activities, developing a demonstrator for a 4U CubeSat Compton Telescope (COMCUBE) prototype, that may offer a game changing GRB polarimetric capability in the few hundred keV range.

Led by LIP, the GLOSS project started in July 2021 in the framework of ESA Euro Material Ageing program. This project is being developed in collaboration with University of Beira Interior (UBI), Italian National Institute for Astrophysics (INAF), the University of Ferrara (UF) and the Istituto dei Materiali per l'Elettronica e il Magnetismo (IMEM), from Parma, Italy. The goal is to characterize the effects of orbit proton radiation environment on CdZnTe (CZT) samples onboard the ISS Bartolomeo platform. This is interesting because our group is developing CZT based detectors for the main instrument of high-energy space astrophysical telescopes operating in Low-Earth Orbit (LEO).

The TGF and High-energy astrophysics Observatory for gamma-Rays on board the Space Rider (THOR-SR) mission is a high-energy astrophysics pathfinder mission designed to explore a range of phenomena that includes gamma-ray astrophysics' emissions such as the Crab Nebula or GRB emissions, space weather and terrestrial gamma-ray flashes (TGFs). Furthermore, it will validate polarization all-sky operation mode and high-energy onboard instrumentation technologies for TRL > 7. This project has extensive synergies with funded FCT project "Terrestrial Gamma-ray Flash Science and Monitoring for Aviation Safety" addressing a major aviation safety question concerning the TGF emission effects on the health of aircraft crews and passengers that may have a real impact on the aircraft safety standards.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Rui Curado Silva	EU	30.000 €	2020-03-02 to 2024-12-01	871158-AHEAD 2020 / Integrated Activities for the High Energy Astrophysics Domain
Rui Curado Silva (Jorge Maia)		106.153 €	2021-06-01 to 2024-06-30	4000136945 GLOSS / GLOSS: Gamma-ray Laue Optics and Solid State detectors (PRODEX Experiment Arrangement No. 4000136945)
Rui Curado Silva (Jorge Maia)	FCT	49.966 €	2022-01-01 to 2023-06-30	EXPL/FIS-PAR/0333/2021 / Terrestrial Gamma-ray Flash Science and Monitoring for Aviation Safety

i-Astro

Overview

Our research activities are currently divided in three lines of work:

1. In the **High-energy astrophysics instrumentation** line of work our research activities are part of two different gamma-ray observatories' proposals with the same objective to study the gamma-ray Universe, however proposing two different types of space platforms: a cubesat constellation (AHEAD); and a probe class NASA satellite (AMEGO).

1.1 In the framework of AHEAD WP11, we are contributing to the development of the COMCUBE prototype, a demonstrator of a 4U cubesat for a future constellation high-energy observatory. Our group was responsible for COMCUBE polarimetric performance and is contributing for the FPGA development.

1.2 In order to optimize the mission design and validate the instrument' s performances, we have been simulating the polarimetric performance with special focus in GRBs and blazars. Prototype testing together with NASA partners is foreseen.

2. **The GLOSS project** with the goal of evaluation of the proton radiation hardness in CdTe detectors in context of a LEO mission evolved to ESA Euro Material Ageing experiment onboard ISS. Leaded by LIP, in collaboration with UBI, INAF, UF, Active Space and IMEM, from Parma, is being set the GLOSS experiment onboard the ISS, where a set of CZT crystals for high-energy astrophysics instrumentation will be tested under the ISS orbit environment with the objective to study its effects on the detectors' performances, by analyzing its response before and after the flight. The launch to the ISS is scheduled to beginning 2024.

3. **The THOR-SR mission**'s main goals are to measure gamma-ray astrophysics' emissions, to perform space weather measurements and terrestrial gamma-ray flashes (TGFs) monitoring. The mission's scientific payload is based on CdTe and Si detectors with a large field of view (up to 2 sr) provided by a four-layer stack detector. It will operate in the 0.1-10 MeV energy range and will perform spectroscopy, imaging, time variability, and polarimetry.

Assessment of the past year: objectives vs. achievements

Below, the objectives for the past year are organized according to the lines of work defined above:

1. In the AHEAD line of work the assessment of objectives vs. achievements is the following:

1.1 As stated i-Astro is taking part in the COMCUBE scientific payload prototype integration task of AHEAD2020 WP11, in particular in the development of COMCUBE FPGA system in order to allow coincidence gamma-ray interactions' measurement and consequently Compton polarization measurements.

1.2 In the framework of the AMEGO consortium, the small size prototype experiment at the Duke University beamline was postponed, likely to end 2023 or 2024.

1.3 As stated STRATOSPOLCA flight data analysis was completed. Concerning double-events, single events and multiple events, background level as a function of flight altitude were analysed and published in the proceedings of the "25th ESA Symposium on European rocket & balloon programmes and related research".

2. During 2022 were performed safety screening tests, at ESA ESTEC facilities. The outgassing of ULTEM 1010 Polyetherimide sample support material was assessed. The Atomic Oxygen (ATOX) screening tests of CZT, Ge and Si sample sets were performed revealing significant discoloration and flaking of CZT sample support material, requiring new design. The CZT crystals pre-flight tests before the flight in ISS orbit environment were still not performed, since the flight to ISS was delayed, probably to 2024.

3. In the 2022 TGF Monitor line of work the assessment of objectives vs. achievements is the following:

3.1 TGFs were simulated based on data from space borne instruments, that were recorded by different space gamma-ray instruments in various geographic regions. Several improvements were implemented in the dose calculation code of aviation crew and passengers. Simulation of gamma-ray flux and spectrum generated in the relativistic runaway electron avalanche was still not performed.

3.2 After the THOR Space Rider experiment was selected by ESA, the Interface Request Review (IRD) was set together with our industrial partners Active Space Tecnhnologies and Advacam. The Requirements Review and Payload Design Review (PDR) started and the Payload Safety Document has been started together with the Space Rider team. A preliminary payload simulation model was built to estimate the scientific potential of this detector as a TGF monitor, but also a small scientific high-energy all-sky monitor.

Lines of work and objectives for next year

The objectives in the main lines of work for 2023 are:

1. **AHEAD, High-energy astrophysics instrumentation**

1.1 AHEAD2020 will enter in its fourth year. i-Astro will take part in the COMCUBE scientific payload prototype integration task of AHEAD2020 WP11. In particular we will continue to participate in the development of the COMCUBE FPGA system. A prototype is schedule to CNES high-altitude balloon from Canada by the end of 2023, beginning of 2024.

1.2 In the framework of the AMEGO consortium, i-Astro will contribute to the simulation with MEGAlib toolkit, of AMEGO polarimetric performances for GRBs and blazars as a function of time as well as the number of potential observable GRBs/year vs minimum detectable polarization.

2. **GLOSS:** In order to assess CZT crystals detection parameters degradation after one year of flight exposed to ISS orbit environment, scientific performance tests will be performed under CZT crystals, throughout 2023. A new methodology to monitor the displacement damage coefficients caused by proton radiation will be introduced and developed: a methodology based in the analysis of current and charge pulses of CZT detectors. The launch of the samples to the ISS will take place probably in 2024.

3. **THOR project** activities for 2023 include both simulation work and payload instrument integration and experimental testing.

3.1 THOR-SR payload requirements review and PDR will be concluded. Assembly Integration Validation and Testing task of the scientific instrument will be initiated. The 16 CdTe and 2 Si will be received and assembled with the readout electronics. The onboard computer data acquisition and software implementations will also be initiated. Payload enclosure will be built by Active Space Technologies. TVAC test plan will elaborate and Payload Safety Document will be set together with Space Rider team.

3.2 Payload mass model simulations will be performed to estimate the scientific potential of this detector as a TGF monitor but as well as a small scientific high-energy all-sky monitor of the brightest gamma-ray sources in the sky: GRBs and the Crab Nebula.

Medium-term (3-5 years) prospects

i-Astro 2023-27 research plan consists of the development of innovative concepts in order build a new generation of space instruments for the orbital environment and for high-energy astrophysics, in the framework of future mission proposals such as AMEGO or COMCUBE.

In AHEAD2020, we expect to develop new gamma-ray detectors for high energy astrophysics, with polarimetric capabilities for future CubeSat mission concepts, since the European Commission is prioritising low-cost platforms for space science missions. This cubsat demonstrator will allow to set a new gamma-ray mission proposal for a future ESA or EU call based on a cubesat constellation allowing fine high-energy astrophysics at a lower cost, faster launch solutions and high redundancy.

We expect that AMEGO mission, will be selected by NASA in the next Probe-Class call. In the framework of AMEGO we will contribute to develop the first laboratorial prototype and space instrument capable to perform pair-production and Compton polarimetry, providing a wider gamma-ray polarimetry window with a vast scientific potential in high-energy astrophysics.

The GLOSS experiment will allow to assess the effects of the exposure of the crystals to the ISS orbit environment, providing unprecedented estimation of performance degradation at LEO, therefore precious guidelines for future high-energy gamma-ray telescope design. Alternative materials will be proposed for future Euro Material Ageing calls and complementary experiments will be performed at the new ICNAS cyclotron beamline (protons up to 70 MeV). Furthermore, we intend to perform future experiments on orbital radiation effects with detector crystals integrated in active mode onboard the Space Rider.

THOR-SR pathfinder mission aboard the Space Rider validates the all-sky operation mode, including polarimetric capabilities, at the highest TRLs (> 7), providing a very relevant conclusion for the future design of high-energy telescopes. Furthermore, this experiment will leverage our research on the effects of the orbital environment on scientific instruments since it will operate exposed to particle radiation in the LEO and to solar proton events. This experiment will also pave the way to develop a CdTe monitor for aviation safety applications, addressing the potential risks of TGFs to human health. The conclusions of this experiment will allow to scale this concept to a smaller monitor suitable to operate on board commercial flight aeroplanes.

SWOT Analysis

Strengths and Opportunities

i-Astro is leading the GLOSS project international team, the TGF Monitor Space Rider experiment and the group is a partner of two major international projects in high-energy astrophysics: AHEAD2020 European project and AMEGO NASA mission. Our participation in these consortia is the consequence of our expertise on high-energy astrophysics polarimetry for more than one decade, combining simulation work and experimental testing. AHEAD2020 activities provide institutional and technical links (simulation tools, detector technology and scientific facilities) that improve our research potential. In case AMEGO will be selected for launch, beyond the potential scientific breakthrough provided by the first gamma-ray space polarimeter, it would be the first time that a Portuguese research team takes part in the main instrument development of a scientific mission launched by NASA. The GLOSS project provides an outstanding opportunity, under ISS orbital environment, to estimate performance degradation at LEO, therefore precious guidelines for future high-energy gamma-ray telescope design. The Space Rider will provide a unique opportunity to develop space scientific instruments for astrophysics and TGF observation with optimal design to operate in LEO.

Weaknesses and Threats

Last decade lack of national funding has compromised seriously project funding, equipment acquisition, as well as the number of grants and contracts available for young researchers as well as senior researchers, including the group coordinator. Salaries are very low and not in line with the responsibilities of some of the main researchers in this project, which is an additional source of human resources instability. The LIP / UC Physics Department facilities are not up to date for fine scientific research activities, for instance mass device laboratorial plug sites are not uniformized and radioactive handling equipment is scarce and overused.

i-Astro

Publications

1 Article(s) in international journals (with direct contribution from team)

- *"All-sky Medium Energy Gamma-ray Observatory eXplorer mission concept"*, Regina Caputo, Marco Ajello, Carolyn A. Kierans, Jeremy S. Perkins, Judith L. Racusin, Luca Baldini, Matthew G. Baring, Elisabetta Bissaldi, Eric Burns, Nicholas Cannady, Eric Charles, Rui M. Curado da Silva, et.al, Journal of Astronomical Telescopes, Instruments, and Systems, Vol. 8, Issue 4, 044003 (October 2022).

1 International Conference Proceedings

- *"AMEGO-X Mission Overview"*, Caputo, Regina ; Perkins, Jeremy ; Racusin, Judith ; Ajello, Marco; Kierans, Carolyn; Fleischhack, Henrike ; Negro, Michela; Zhang, Haocheng; Venters, Tonia; Cannady, Nicholas; Bissaldi, Elisabetta; Karwin, Christopher; Lewis, Tiffany; Sheng, Yong ; Lien, Amy ; Steinhebel, Amanda; Shawhan, Peter; Baring, Matthew ; Martinez-Castellanos, Israel; Wadiasingh, Zorawar search by orcid; Woolf, Richard; Prescod-Weinstein, Chanda; Kocevski, Daniel; Razzaque, Soebur; Tak, Donggeun; Suda, Yusuke; Zoglauer, Andreas; Howell, Eric; Mazziotta, Mario Nicola; Curado da Silva, Rui; Valverde, Janeth; Wulf, Eric; Metcalfe, Jessica; McEnery, Julie; Kurahashi Neilson, Naoko, AAS High Energy Astrophysics Division meeting #19, id. 404.03. Bulletin of the American Astronomical Society, Vol. 54, No. 3

Presentations

3 Oral presentations in international conferences

- H. Neves, R.M.Curado da Silva, P. Afonso, N. Auricchio, I. Carmo, E. Caroli, M. Ferreira, R. Gameiro, J. Gonçalves, A. Lemos, J. M. Maia, D. Marques, B. Matos, A. Mendonça, M. Moita, A. Neves, M. Neves, A. Oliveira, I. Oliveira, J. Pereira, P. Póvoa, S.Rodrigues, R. C. Roque, J. Silva, J. Silveirinha, M. Simões, G. Smith, J. Sousa, D. Torres: *"Stratospheric polarimetry with cadmium telluride array"*, 2022-05-05, 25th ESA Symposium on European rocket & balloon programmes and related research (PAC Symposium), Biarritz, France
- E. Virgilli, E. Caroli, S. Del Sordo, L. Ferro, M. Moita, J. B. Stephen, P. Rosati, O. Limousin, P. Laurent, A. Meuris, H. Allaire, N. Auricchio, R. M. Curado da Silva, J. M. Maia, I. Kuvvetli, C. Budtz-Jørgensen: *"Gamma-ray spectro-polarimetry with a Laue optics balloon payload"*, 2022-05-05, 25th ESA Symposium on European rocket & balloon programmes and related research (PAC Symposium), Biarritz, France
- R. M. Curado da Silva; Joana Mingacho; Jorge Maia: *"Fenómenos troposféricos com riscos potenciais para a aviação "*, 2022-10-14, Portugal Air Summit, Ponte de Sor, Portugal

1 Poster presentation(s) in international conference(s)

- R. M. Curado Da Silva, J. M. Maia, J. Sousa, P. Póvoa, J. Mingacho, G. Falcão, J. Gonçalves, G. Salgado, M. Moita: *"Large Field CdTe Monitor for Astrophysics and TGF Science on board the Space Rider"*, 2022-11-07, IEEE Nuclear Science Symposium, Milano, Italy

1 Oral presentation(s) in national or international meeting(s)

- Rui Curado Silva: *"i-Astro group activities"*, 2022-07-10, Jornadas LIP 2022, Coimbra

1 Outreach seminar(s)

- Rui Curado Silva: *"Da Terra à Lua"*, 2022-01-19, , Agrupamento de Escolas do Paião

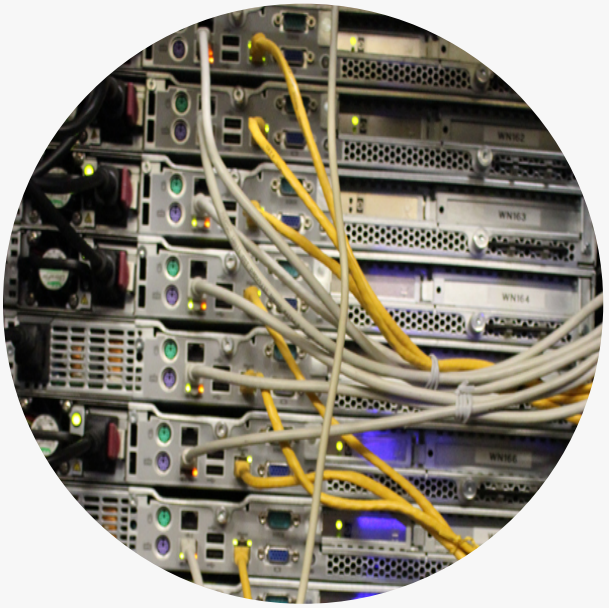
Theses

1 PhD

- Alexandre Fonseca Trindade: *"Study of noble gases mixtures characteristics as a detection medium"*, 2016-05-01 , (ongoing), UC, Supervisor(s): Filomena Santos, Rui Curado Silva

5 Master

- Bárbara Matos: *"Investigation of inorganic scintillator detectors with photodiode readout"*, 2021-09-01 / 2022-07-26, (finished), UC, Supervisor(s): Rui Curado Silva,
- Henrique Neves: *"From the Concept to Development of Astrophysics Payloads for Gamma Radiation Studies"*, 2020-09-14 / 2022-09-23, (finished), UC, Supervisor(s): Rui Curado Silva, Jorge Maia
- José Sousa: *"Space Rider CdTe detector experiment payload development"*, 2021-09-01 , (ongoing), UC, Supervisor(s): Rui Curado Silva, Jorge Maia
- Pedro Póvoa: *"FPGAs for CdTe 2D detectors for High-Energy Astrophysics "*, 2021-09-01 , (ongoing), UC, Supervisor(s): Rui Curado Silva,
- André Neves: *"ASTROFÍSICA MULTI-MENSAGEIRA COM O TELESCÓPIO AMEGO DA NASA"*, 2022-09-01 , (ongoing), FCTUC, Supervisor(s): Rui Curado Silva,



[Scientific Computing]

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RESEARCH / SCIENTIFIC COMPUTING

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Distributed Computing and Digital Infrastructures

Principal Investigator:
Jorge Gomes (100)

3 ***Researcher(s):***
António Pina (75), João Pina (99), Mário David (100)

12 ***Technician(s):***
Carlos Manuel (100), Catarina Gonçalves (84), Catarina Ortigão (49), Henrique Carvalho (50), Hugo Gomes (100), José Aparício (100), João Paulo Martins (100), Miguel Viana (67), Nuno Ribeiro Dias (100), Samuel Bernardo (100), Tiago Gonçalves (25), Zacarias Benta (40)

5 ***External collaborator(s):***
António Esteves, César Ferreira, Isabel Campos, José Rufino, Vítor Oliveira

Total FTE:
12.9 (PhD 2.7)

Notes:	**17** Collaboration notes
International conferences:	**11** Oral presentations
National conferences:	**4** Oral presentations **1** Poster
Nat.& Internat. meetings:	**1** Oral presentation
Collaboration meetings:	**2** Oral presentations
Advanced Training Events:	**2** Oral presentations
Seminars:	**2** Seminars **1** Outreach seminar
Articles in Outreach Journals:	**2** Articles in Outreach Journals
Data sets, software packages and other digital tools:	**3** Datasets
Organized events:	**3** Events

Executive summary

The Distributed Computing and Digital Infrastructures Group provides information technology services to support research, innovation, education, outreach and administrative activities at LIP. The group has extensive experience in delivering compute and data oriented services for research, including the operation of the Portuguese Tier-2 facility integrated in the CERN Worldwide LHC Computing Grid (WLCG) supporting the ATLAS and CMS experiments. The group activities bridge at international level with e-infrastructures and initiatives such as the European Grid Infrastructure (EGI), Iberian Grid Infrastructure (IBERGRID), European Open Science Cloud (EOSC) and EuroHPC. In this context the group collaborates with several research communities beyond High-Energy Physics.

The development of the group competences is backed by the participation in research, development and innovation projects at national and international level. The group is participating in several European projects applied to compute and data intensive science, namely: In EGI-ACE, delivering the middleware management for the EGI infrastructure, supporting cloud applications and working on solutions for high performance computing (HPC) integration; In EOSC-Future, coordinating the software management activities; In DT-Geo providing solutions for containerisation, integration and software quality for a digital twin on geophysical extremes; In interTwin delivering quality and software management for a generic framework to support interdisciplinary digital twins; In AI4EOSC working in the development, provisioning and quality assurance of the DEEP AI platform; In iMagine providing support to the use of the DEEP AI platform for aquatic science; The group is also participating in the BigHPC project in the framework of the UT-Austin-Portugal program contributing to the quality assurance and integration of a platform for big data applications.

In 2022, the group finalised the European projects: EOSC-Synergy where it worked in developing a platform for quality assurance as-a-service for research software, services and data; and EuroCC, where it contributed to establish the national competence center for high performance computing in the framework of EuroHPC. A new follow-up project EuroCC-2 is approved and will start in the beginning of 2023.

The group leverages its expertise to deliver scientific computing services to the wider Portuguese scientific and academic communities via the Portuguese National Distributed Computing Infrastructure (INCD), of which LIP is the main technological partner. INCD is a digital infrastructure in the FCT roadmap of research infrastructures. Through INCD, the group is also engaged in national activities related to High Performance Computing (HPC) in the context of the national advanced computing network (RNCA). The group is also developing the national catch-all research data repository in collaboration with FCT.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Jorge Gomes		223.000 €	2017-07-18 to 2022-12-21	INCD 01/SAICT/2016 - nº 022153 / Portuguese National Distributed Computing Infrastructure
Jorge Gomes		433.000 €	2019-09-01 to 2022-10-31	EOSC-synergy grant 857647 / European Open Science Cloud – Expanding Capacities by Building Capabilities
Jorge Gomes		249.561 €	2020-03-31 to 2023-03-31	LISBOA-01-0247-FEDER-045924 // POCI-01-0247-FEDER-045924 / Big HPC - A Management Framework for Consolidated Big Data and HPC
Jorge Gomes (João Pina)		347.051 €	2020-09-01 to 2022-12-31	EUROCC / Innovating and Widening the HPC use and skills base
Jorge Gomes		196.238 €	2021-02-01 to 2023-08-31	EGI-ACE / Implementing the European Open Science Cloud
João Pina (Jorge Gomes)		160.375 €	2022-01-01 to 2024-12-31	EOSC-Future / EOSC-Future - EU-funded H2020 project that is implementing the European Open Science Cloud (EOSC)
João Pina (Mário David)		29.999 €	2022-03-21 to 2024-03-20	CERN/FIS-COM/0018/2021 / Support for the ATLAS and CMS tier-2 in the context of the Portugal - CERN WLCG MoU
Jorge Gomes (Mário David)		342.812 €	2022-06-01 to 2025-05-31	interTwin (ID:101058386) / An interdisciplinary Digital Twin Engine for science
Mário David (Jorge Gomes)		222.125 €	2022-06-01 to 2025-05-31	iMagine / Imaging data and services for aquatic science (Grant Agreement 101058625)
Jorge Gomes (Mário David)		542.875 €	2022-06-01 to 2025-05-31	DT-GEO / A Digital Twin for GEOphysical extremes
Mário David		350.250 €	2022-06-01 to 2025-05-31	AI4EOSC / Artificial Intelligence for the European Open Science Cloud
Jorge Gomes (Mário David)		19.999 €	2022-12-01 to 2023-12-31	POCI-05-5762-FSE-000438 / Integration services for the implementation of an FCT research data repository based on the Dataverse software.
João Pina (Jorge Gomes)		146.000 €	2023-01-01 to 2025-12-31	EuroCC 2 / National Competence Centres for High Performance Computing

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Overview

The group activities are organized in four main areas:

- Participation in R&D&I projects in information and communication technologies (ICT) to develop new competences and capabilities. The group participates in projects addressing several aspects of scientific data processing including: federation of compute and storage resources, massive data processing, high performance computing, cloud computing, network technologies, authentication and authorization, data repositories, machine learning, Linux containers and software quality assurance, among others.
- Scientific computing and data processing services. Delivery of services and expertise related to processing farms, cloud computing and data storage. Participation and liaison with international digital infrastructures and initiatives such as WLCG, EGI, IBERGRID and EOSC. Delivery of compute and data services to the wider research community via the Portuguese National Distributed Computing Infrastructure (INCD). Participation in the national advanced computing network (RNCA).
- Delivery of institutional services to LIP, including support to administrative services, network related services, desktops, laptops, security, authentication and authorization, printing services, data protection among others.
- Web services, web development, graphic design, communication and multimedia services, aiming at supporting outreach, dissemination, exploitation, administration, education and research activities.

These activities integrate researchers, engineers and technicians from LIP complemented by staff from INCD under the group coordination. The group has collaborators at the LIP centres in Lisbon and Minho. The delivery of compute and data intensive services and participation in R&D&I activities is performed in close collaboration with INCD, which provides the compute and data infrastructure resources.

Assessment of the past year: objectives vs. achievements

The improvement of the LIP IT systems continued in 2022 with the renewal of virtualisation servers and preparation for replacement of mail and web servers. Improvements in the Lisbon and Coimbra housing facilities also took place.

The WLCG Tier-2 supporting ATLAS and CMS executed 471,000 jobs and delivered 165,631,000 HEP Spec06 normalized processing hours, yielding a 70% increase. This improvement was possible thanks to hardware donated by ATLAS/CERN. The storage was also improved with 500 TB of additional capacity acquired via an FCT project. Overall the Tier-2 reliability was 97%.

LIP is deeply engaged in INCD, a multidisciplinary digital infrastructure in the FCT roadmap of research infrastructures. LIP participated in the management of the INCD Association and coordinated all technical activities. LIP coordinated the INCD projects including: implementation of a catch-all repository for research data in collaboration with FCT; implementation of Earth observation services exploiting Copernicus data in the C-Scale project; delivery of cloud services to support thematic services in biodiversity and coastal engineering in the EGI-ACE project; integration of compute and data services in the EOSC-Synergy project; and hosting of deep learning services in the iMagine project. Steps towards a collaboration in the European Partnership Agriculture of Data started.

Under the LIP coordination, in 2022, INCD delivered 43,050,000 CPU hours to computing projects in all domains. An international tender to improve the INCD capacity was performed, resulting in 7000 CPU cores, 3 PB of online storage and up to 20 PB of tape storage to serve the Portuguese research community. In Lisbon the existing HPC cluster was complemented and the connectivity was upgraded to 100 Gbps, and in Vila Real a new operations centre was created to provide cloud and HPC services. Tape based storage was installed in Coimbra. Partial migration of the Bob supercomputer to Lisbon started in a joint effort of LIP, FCT and INCD.

LIP represented INCD in the national advanced computing network (RNCA) council and related work-groups. Within the RNCA activities, LIP provided support to computing projects from the 2nd FCT call for advanced computing projects (CPCA), and participated in the preparation and evaluation of the 3rd CPCA whose projects will start in 2023.

In the EuroHPC initiative for a world class supercomputing ecosystem in Europe, LIP finalised the EuroCC project that established a national competence center for HPC. LIP coordinated the awareness and communication task and participated in the support, consulting, and training. A follow-up project EuroCC-2 was prepared and will start in 2023. LIP also participated in the BigHPC project with TACC and INESC TEC developing a framework to support Big Data applications in HPC environments; the contributions were focused on software quality assurance and validation pilots.

LIP ensured the liaison with the EGI and IBERGRID infrastructures that federate computing infrastructures across Europe. The CERN WLCG is one of the supported communities under EGI and IBERGRID; other scientific domains supported by LIP with INCD include astroparticles, biodiversity, life sciences, health, coastal, estuarine and civil engineering, structural biology, materials science, computer science and oceanography among others. LIP coordinated the IBERGRID operations and the national participation in EGI at the technical level and in the EGI council.

Participation in the European Open Science Cloud (EOSC) continued. The EOSC-Synergy project aiming to align infrastructures and policies in ES, PT, UK, CZ, DE, SK, PL and NL, finished with a very successful

review where the work coordinated by LIP was highly praised. The consortium was encouraged to exploit these developments and apply to a follow-up project. LIP worked in the development of a platform for quality assurance and assessment of software, services and data; and definition of quality criteria for software and services. The EGI-ACE project continued with LIP participating in the HPC integration, delivery of services for machine learning, middleware management for the EGI federation, implementation of new software repositories for EGI middleware, and federation of the Iberian nodes of the Global Biodiversity Infrastructure (GBIF). The EOSC-Future project continued with LIP providing software and IT service management for the EOSC core.

New projects started: DT-Geo is a digital twin for earthquakes, volcanoes and tsunamis; interTwin will develop an interdisciplinary digital twin engine; AI4EOSC continues previous work on a cloud platform for deep learning and AI; and iMagine applies the AI4EOSC developments to aquatic sciences.

Finally LIP organised the IBERGRID 2022 conference joining Iberian researchers, developers and infrastructure managers in Faro. IBERGRID 2022 also included the first EOSC tripartite event in Portugal and Spain joining the EC, funding agencies and researchers.

Lines of work and objectives for next year

IT services

The improvement of the LIP core IT services in the framework of the Associate Laboratory programme will continue in 2023. The ongoing improvements will be finalised in Lisbon and extended to Coimbra. The improvement plans include upgrades of network, storage and central services equipment.

WLCG and Tier-2

The evolution of WLCG and related computing models will be followed. The group will continue working with all stakeholders to seek solutions for the sustainability and improvement of the LIP computing facilities with a particular emphasis in the WLCG Tier-2.

EGI, IBERGRID and EOSC

LIP will ensure the operations coordination of the IBERGRID infrastructure that federates scientific computing centres across the Iberian region and enables a common participation in the pan-European EGI infrastructure. LIP will continue representing FCT in the EGI council and ensuring the technical and governance liaison. The INCD computing services are federated in IBERGRID and EGI, and LIP will continue operating them and supporting international research communities. In the scope of the EGI activities, LIP will continue participating in the EGI-ACE project, working on HPC integration, middleware management and delivering computing services via INCD. In EOSC-Future the service management activities will continue. Both EGI-ACE and EOSC-Future will finish in 2023. The group will seek further funding opportunities.

R&D&I projects

Four new European projects started in September 2022. The projects AI4EOSC and iMagine are focused on deep learning applications. AI4EOSC will continue the work started in DEEP-Hybrid-DataCloud towards a platform for machine learning, while iMagine leverages the same developments to support marine and freshwater research. The projects DT-GEO and interTwin are focused on digital twins in multiple domains from the Earth sciences mimicking different system components (atmosphere, ocean, land, lithosphere), to high energy physics, radio-astronomy, astroparticle physics, climate research, and environmental monitoring. LIP's participation will be strongly focused on applying the expertise in software, services and data quality, as well as IT service management, and Linux containers to the digital twins and AI platform. These projects also relate to the EGI and IBERGRID development and community support activities. The participation in the BigHPC project with TACC, INESC-TEC and the Portuguese company WAVECOM will finish in 2023 with the validation of the BigHPC software framework for big data applications.

EuroHPC and RNCA

The participation in the national advanced computing competence center (NCC) in the EuroCC project will continue in the framework of the new project EuroCC-2 to be started in 2023. The main focus will be put on the awareness creation and communication task coordinated by LIP, and in the training and knowledge transfer activities. The project is coordinated by FCT and has the support of the EuroHPC JU. These activities relate closely to the national advanced computing network that encompasses centres for computing, visualization and support at national level. LIP will participate in the RNCA activities also bridging with INCD. These include the support to the FCT computing projects approved under the 3rd call for advanced computing projects allocated to INCD.

INCD

The funding from the FCT roadmap of research infrastructures finished in December 2022, and INCD will be crossing a funding gap of unknown duration. The focus will be put in maintaining the infrastructure operational. The equipments acquired in the end of 2022 will be made fully available in the first months of 2023. This will include HPC capacity in Lisbon and Vila Real, as well as data protection capacity in Coimbra. A new cloud service instance will be implemented in Vila Real and will be made available in spring. Similarly the migration of HPC equipment from Minho to Lisbon will be completed. In addition LIP will coordinate the INCD participation in the projects EGI-ACE, C-Scale and iMagine where INCD is supporting the integration and delivery of cloud-based services for specific research communities.

Data Repositories

Collaboration with FCT and INCD towards a catch-all scientific data repository will continue. Improvements to the Dataverse data repository framework are being be implemented by the group. The initial release of the repository service is expected to take place in the first semester. Solutions for tape based storage will be pursued to further exploit the tape library capacity and provide a cost effective solution for long term storage. The possibility of integrating tape based storage with the data repository will be analysed. Finally the collaboration in the European partnership for agriculture of data is expected to continue with piloting of a data lake.

Medium-term (3-5 years) prospects

Participation in international digital infrastructures and initiatives will continue with participation in EGI, IBERGRID and EOSC. Participation in EOSC task forces and projects is ongoing in EGI-ACE and EOSC-Future until 2023/2024. The national competence center in EuroCC/EuroHPC will have a follow-up project. A proposal for a follow-up project to EOSC-Synergy will be also pursued in 2023. Participation in further projects will be considered in the context of Horizon Europe and Digital Europe.

With the ramp up of LHC luminosity enlarging the Portuguese Tier-2 is of strategic importance. Opportunities to improve the Tier-2 will be followed within the scope of LIP and INCD. The WLCG architecture and the Portuguese Tier-2 will likely evolve over the coming years.

The funding for INCD from the FCT research infrastructures roadmap finished in 2022. The future of the roadmap is currently uncertain. The participation in the national advanced computing network may offer an alternative framework, with limited assistance already being provided by FCT. Collaboration with FCT in the area of scientific data repositories will continue leveraging the INCD capacity and the group expertise from the participation in EOSC projects.

The projects interTwin, DT-GEO, AI4EOSC and iMagine, started in September 2022. They will provide a framework to continue the line of work and further exploit the achievements over the next 3 years.

SWOT Analysis

Strengths

- Extensive experience in scientific computing, software integration, software management and quality assurance.
- Participation in international scientific e-infrastructures and initiatives.
- Operating the Portuguese WLCG Tier-2 under the CERN LHC computing MoU.
- Participation in several European projects.
- Partnership with FCCN and LNEC and collaboration with other organizations.
- Participation in the national advanced computing competence center in EuroCC.
- Participation in the FCT roadmap of research infrastructures of strategic interest.
- Participation in the Portuguese Advanced Computing Network.
- Participation in EGI, IBERGRID and in EOSC projects.

Weaknesses

- Heavy administrative burden severely compromises the effective use of the human resources.
- Lack of compute and storage resources to address opportunities and user requirements.
- Lack of sustainability with many activities being supported on a voluntary and/or best effort basis.
- Highly overworked team.

Opportunities

- Potential for engagement with a wide range of research communities.
- Participation in activities related to High Performance Computing.
- Participation in open data and digital repositories related activities.
- Potential for industrial and e-government applications.

Threats

- Lack of resources for the LHC and other large requirements.
- Lack of sustained funding for operational costs.
- Exacerbated focus towards supercomputing at national and European levels.
- Increasingly higher competition for funding.
- Extremely difficult to contract and retain skilled personnel.
- Uncertain future for the FCT infrastructures roadmap.

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Publications

17 Collaboration notes with internal referee

- *"BigHPC Deliverable 5.2 - Intermediate report on the integration, validation and pilot activities"*, A.Ruhela (TACC), J.Paulo (INESC TEC), J.Silva (Wavecom), M.Miranda (INESC TEC), M.David (LIP), R.Macedo (INESC TEC), T.Evans (TACC), S.Bernardo (LIP), S.Harrell (TACC), T.Gonçalves (LIP), Z.Benta (LIP), BigHPC deliverable
- *"EOSC-SYNERGY EU Milestone: M3.5 All thematic services all with a working CI/CD pipeline"*, J.Gomes, P.Orviz, F.Aguilar, S.Bernardo, EOSC-synergy project milestone
- *"EOSC-synergy: A Set of Common Service Quality Assurance Baseline Criteria for Research Projects"*, M.David, P.Orviz, J.Gomes, S.Bernardo, I.Campos, G.Moltó, M.Caballer, ,
- *"EOSC-Synergy EU Deliverable: D3.4 Final release of the SQAaaS"*, J.Gomes, P.Orviz, S.Bernardo, M.David, D.Naranjo, G.Molto, I.Campos, EOSC-synergy project deliverable
- *"EGI-ACE D7.3 Final version HPC integration Handbook"*, E.Fernández; F.Antonio; H.Bayındır; I.Díaz; M.Dulea; C.Fernández; J.Gomes; A.Lahiff; D.Southwick; D.Spiga; T.Tanin; G.Sipos;, EGI-ACE deliverable
- *"A set of Common Software Quality Assurance Baseline Criteria for Research Projects"*, P Orviz (IFCA), A García (IFCA), C Duma (INFN), G Donvito (INFN), M David (LIP), J Gomes (LIP), DEEP-Hybrid-DataCloud project deliverable
- *"EOSC-Synergy EU Deliverable: D3.5 Final report on technical framework for EOSC FAIR data principles implementation"*, F.Aguillar, W.Steinhoff, V.Tykhonov, I.Bernal, J.Gomes, V.Kozlov, V.Tran, EOSC-synergy project deliverable
- *"INCD Mi1.1 Internal Coordination and Administration Structure"*, J.Gomes, C.Ortigão, INCD milestone
- *"INCD Mi6.3 All Centres Fully Operational"*, Jorge Gomes, João Pina et al, INCD milestone
- *"INCD Mi3.1 Relation with Users Planning and Set-up of the Activity"*, J.Gomes, C.Ortigão, INCD milestone
- *"INCD Mi2.3 Final Event"*, J.Gomes, J.Pina, INCD milestone
- *"INCD Mi8.3 Revised Documentation Materials"*, J.Pina, M.David, J.Gomes, INCD milestone
- *"INCD Mi5.3 Comprehensive Set of Services Available"*, J.Gomes, J.Pina, INCD milestone
- *"INCD Mi1.4 Business and sustainability model"*, J.Gomes, J.Pina, INCD milestone
- *"EOSC-Synergy Final Technical Report"*, Isabel campos, Jorge Gomes and all WP leaders,
- *"D7.1 - Initial plan for Quality Assurance and data FAIRness"*, Mário David, Alvaro Lopez, Viet Tran, AI4EOSC deliverable
- *"EuroCC D19.3 NCC Portugal Final Report"*, E.Araújo; M.Avillez; P.Alberto; J. Gomes, H. Gomes, J. Pina, C. Manuel, C.Gonçalves; L.Oliveira; T.Silva; R.Vilaça, A.Guerreiro, EuroCC deliverable

3 Datasets, software packages and other digital tools

- *"JePL a library to implement Software Quality Assurance (SQA) checks in Jenkins environments"*, S.Bernardo
- *"MOOC on Software and Service Quality Assurance Essentials"*, M.David, P.Orviz, S.Bernardo, J.Gomes, I.Campos, EOSC-Synergy MOOC
- *"MOOC on Software Quality Assurance as a Service Platform"*, P.Orviz, S.Bernardo, EOSC-Synergy MOOC

2 Articles in Outreach Journals

- *"Software and Service Quality Assurance Essentials"*, M.David, P.Orviz, S.Bernardo, J.Gomes, I.Campos, EOSC-Synergy MOOC
- *"Software Quality Assurance as a Service"*, P.Orviz, S.Bernardo, EOSC-Synergy MOOC

Presentations

11 Oral presentations in international conferences

- Valentin Kozlov, Jorge Gomes, Mário David, Samuel Bernardo et all: *"A quality-based approach for research software and services"*, 2022-02-25, Research Engineering Track at the virtual conference Software Engineering 2022, Virtual, Germany
- Jorge Gomes: *"EOSC Projects: INFRAEOSC-5B EOSC Synergy"*, 2022-10-10, Spain & Portugal EOSC Tripartite Event, Faro
- Jorge Gomes: *"The Portuguese Distributed Computing Infrastructure (INCD) and Related Activities"*, 2022-10-11, IBERGRID 2022, Faro
- Samuel Bernardo, Mário David, Pablo orviz, Jorge Gomes, Isabel Campos, Miguel Caballer, Diana Naranjo: *"EOSC-Synergy Jenkins Pipeline Library"*, 2022-10-11, IBERGRID 2022, Faro
- Mário David, Pablo orviz, Samuel Bernardo, Jorge Gomes, Isabel Campos, Miguel Caballer, Diana Naranjo: *"Quality Assurance Models in the framework of EOSC-Synergy"*, 2022-10-11, IBERGRID 2022, Faro
- Jorge Gomes, Mário David: *"User space containers with udocker "*, 2022-10-12, IBERGRID 2022, Faro
- Jorge Gomes: *" INCD infrastructure "*, 2022-10-12, IBERGRID 2022, Faro
- Zacarias Benta, César Ferreira, Samuel Bernardo, Mário David, Jorge Gomes, João Pina, Miguel Viana: *"C-SCALE OpenEO Deployment "*, 2022-10-13, IBERGRID 2022, Faro
- João Pina, Mário David, Carlos Manuel, Pablo Orviz, Samuel Bernardo: *"Repositories for EGI "*, 2022-10-13, IBERGRID 2022, Faro
- Zacarias Benta, César Ferreira, Jorge Gomes, Samuel Bernardo, Mário David, João Pina, Miguel Viana: *"Developing a Distributed and Fault Tolerant Dataverse Architecture "*, 2022-10-13, IBERGRID 2022, Faro
- Samuel Bernardo: *"Linking GitOPS towards fast innovation over BigHPC "*, 2022-10-13, IBERGRID 2022, Faro

1 Oral presentation(s) in national or international meeting(s)

- Jorge Gomes and WP3 members: *"Fostering Quality - The EOSC-Synergy approach"*, 2022-12-15, Project final review, Virtual

4 Presentations in national conferences

- Jorge Gomes: *"Computing and Collaboration at LIP"*, 2022-05-16, Ciência 2022, Lisboa
- Jorge Gomes: *"National Distributed Computing Infrastructure"*, 2022-05-16, Ciência 2022, Lisboa
- Jorge Gomes: *"Infraestrutura Nacional de Computação Distribuída"*, 2022-06-02, Jornadas de Computação Científica 2022 FCCN, Politécnico de Viseu

- Jorge Gomes: ***"Novos meios de computação e dados da INCD"***, 2022-11-15, RNCA meeting 2022, LNEC, Lisboa

1 Poster presentation(s) in national conference(s)

- B. Backeberg, Z. Benta, M. David, G. Donchyts, J. Gomes, T. Gonçalves, J. Langemeijer, J. Pina, M. Viana: ***"Detecting land-surface changes from space: Porting the Aqua Monitor application from Google Earth Engine"***, 2022-03-22, First Copernicus National Conference, Évora, Portugal

2 Oral presentations in advanced training events

- Mário David, Jorge Gomes, João Pina: *"Infrastructure for Storage and Sharing"*, 2022-03-07, Training Data Stewards for Life Sciences, Virtual, Portugal
- Jorge Gomes: *"Facilitating access to HPC via Containers"*, 2022-09-19, LatticeNET School on Computing in HEP 2022, Benasque, Spain

2 Seminars

- S.Bernardo: *"Webinar 1: Linking GitOPS towards fast innovation over BigHPC"*, 2022-02-10, BigHPC webinar , Virtual
- S.Bernardo, M.Viana: *"Webinar 6: A deep dive on BigHPC platform delivery into HPC clusters"*, 2022-11-30, BigHPC webinar, Virtual

1 Outreach seminar(s)

- Jorge Gomes: *"Distributed Computing and Digital Infrastructures"*, 2022-03-09, IST students visit , LIP, Lisboa

Organized Events

1 International Conferences or Workshops

- *"IBERGRID 2022"*, [Conf-WS-Int] 2022-10-10 / 2022-10-13, Faro

1 Collaboration Meetings

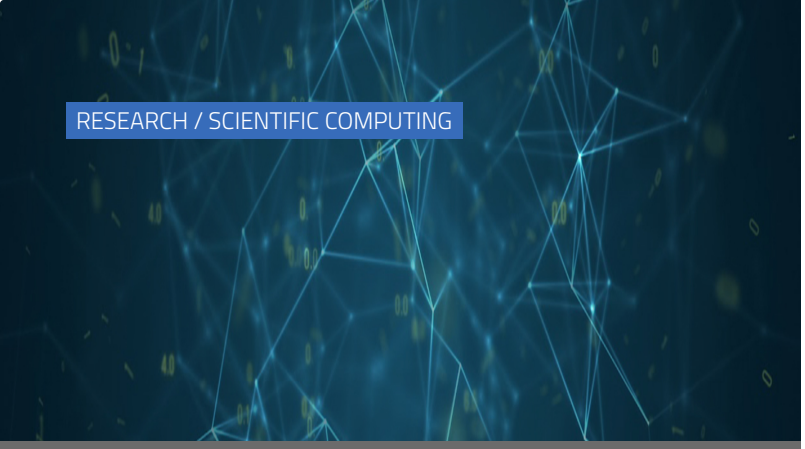
- *"EOSC-Synergy AHM "*, [Coll-Mtg] 2022-10-12 / 2022-10-13, Faro

1 Scientific Meeting

- *"Spain & Portugal EOSC Tripartite Event"*, [Sci-Mtg] 2022-10-10 / 2022-10-10, Faro

3 Advanced Training Events

- *"Course on Computational Biosciences using HPC systems"*, [Adv-Trng] 2022-09-12 / 2022-09-19, Online
- *"SQAaaS Hackathon"*, [Adv-Trng] 2022-10-10 / 2022-10-10, University of Algarve, Faro, Portugal
- *"SQAaaS Hackathon"*, [Adv-Trng] 2022-10-11 / 2022-10-11, University of Algarve, Faro, Portugal



RESEARCH / SCIENTIFIC COMPUTING

SPAC

Social Physics and Complexity

Principal Investigator:
Joana Gonçalves-Sá (80)

3 ***Researcher(s):***
Cristina Mendonça (100), José Reis (100), Lília Perfeito (100)

4 ***Technician(s):***
Hamid Shahzad (15), Hugo Cachitas (75), Paulo Almeida (85), Rita Saraiva (50)

2 ***PhD Student(s):***
Sara Mesquita (100), Íris Damião (92)

1 ***Research Assistant(s):***
Angela Rijo (71)

2 ***Undergraduated Student(s) and Trainee(s):***
Armando Gonçalves, Tiago Miranda

7 ***External collaborator(s):***
David Almeida, Eleonora Tulumello, Irma Varela-Lasheras, João Loureiro, João Oliveira, Pedro Canatário Duarte, Simone Lackner

Total FTE:
8 (PhD 3.8)

Proposals:	**2** Proposals and related studies
International conferences:	**8** Oral presentations **5** Posters
National conferences:	**2** Oral presentations
Nat.& Internat. meetings:	**2** Oral presentations
Advanced Training Events:	**5** Oral presentations **2** Student presentations
Seminars:	**3** Seminars **11** Outreach seminars
Appearances/articles in the media:	**12** Articles in the media
Completed theses:	**1** MSc
Organized Events:	**1** National Conference or Workshop **1** Outreach Event

Executive summary

The LIP Social Physics and Complexity (SPAC) group uses large scale computational tools to study societal challenges, especially in disease forecasting, human behavior, and public policy, using a multidisciplinary approach.

Understanding complexity has always been a hallmark of physics research and, right now, the Digital Revolution is offering radically new ways to study complex human behaviours. There is a growing perception that physics will be fundamental to study sociology and even psychology and leading scientists are calling this new science “Social Physics” and arguing that, in some ways, complexity science will study the physics of human interactions. Therefore, SPAC is a multidisciplinary team with members coming from distinct backgrounds, including Physics, Mathematics and Computer Sciences, but also Biology, Neurosciences, Psychology, and Law. Together, the group takes advantage of “Big-Data” and aims at understanding how individual behaviour impacts on society. SPAC also focuses on the risks that these upcoming technologies might entail, from privacy to human biases, and works to establish guidelines for ethical uses of data science and artificial intelligence.

SPAC’s work is mainly funded by an European Research Council (ERC) Starting Grant to the group’s PI to conduct the research project “Fake News and Real People – Using Big Data to Understand Human Behaviour (FARE)”. In 2022, SPAC furthered the goals of the FARE project, namely by designing the large-scale survey and completing the databases. In September, SPAC was awarded an ERC Proof-of-Concept grant (FARE_Audit) to develop an auditing tool for search engines. One of the PhD students at SPAC was awarded a competitive PhD fellowship and one of the MSc students finished his thesis. Three manuscripts are currently under peer review and the team is actively collecting “big” data. In parallel, SPAC contributed to health pandemic research and policy design, in collaboration with different entities. As part of these efforts, SPAC organized a workshop with different stakeholders in the field, including researchers, medical doctors and data scientists, working in different public and private institutions, and released a proposal for a monitoring system for transmissible respiratory diseases, co-authored by all participants and other external experts.

Funding

PI	Source	Amount	Dates	Project / Description
Joana Gonçalves-Sá	EU/ERC	1.499.84 €	2020-10-01 to 2025-09-30	ERC - FARE / Fake News and Real People – Using Big Data to Understand Human Behaviour (853566)
Joana Gonçalves-Sá	EU/ERC	150.000 €	2022-12-01 to 2024-05-31	ERC - FARE_AUDIT / Fake News Recommendations - an Auditing System of Differential Tracking and Search Engine Results (101100653)

SPAC

Overview

Through theory, experiments, and models, physicists have made fundamental contributions to many different complex fields. Specifically, complexity science tries to identify general principles from systems consisting of a large number of interacting heterogeneous components (parts, agents, humans etc.), resulting in highly non-linear and unpredictable behaviour, with emergent properties. One particularly complex subject is human behaviour and its consequences, from disease spreading to how societies organize. Until now, these problems have been considered quite intractable; however, the so-called Digital Revolution, with its combination of large-scale data sources and a growing toolbox from machine learning and big data analytics, is making it possible to study complex social behaviours, extracting patterns and offering some predictions. The power of this approach is being recognized by physics and computer science departments in many top universities worldwide.

SPAC brings together a strongly multidisciplinary and international team of researchers, who use large scale computational tools and models from social physics to study such complex systems, especially in disease forecasting, human behavior, and public policy. SPAC aims at the development of new mathematical methods to improve our understanding of human actions from a theoretical and first-principles perspective.

The group meets weekly and organizes frequent journal clubs and paper discussions. All group members are involved in different projects and contribute their expertise in collaborative and collegial ways. SPAC currently has 14 members, including students and postdocs, and is divided into three main sub-teams: Health, mostly focused on understanding infectious disease dynamics, FARE, that uses fake news spreading to study human decisions and behaviour, and Ethics, that tries to develop tools to improve privacy in online research.

Assessment of the past year: objectives vs. achievements

In 2022 SPAC consolidated its presence at LIP. SPAC members physically moved and half of the team is working full-time at LIP (the other half alternates between in-person and remote work).

Four main goals were accomplished:

1. Building team capacity, maintaining team spirit and mental health;
2. Finishing a grant that focused on disease control, which implied collecting and analyzing a large dataset of health-related data (in collaboration with the National Ministry of Health);
3. Establishing the foundations of the FARE project, most notably the computational and data infrastructure to support the necessary future analysis and the (almost) completion of the core dataset on fake news and Tweets;
4. Assuring the quality and safety of the data pipelines and processes, complying with the GDPR and the EU ethical and privacy standards. SPAC helped establish LIP's Ethics Committee and submitted a project for evaluation.

Research Team and Funding

The ERC project "Fake News and Real People – Using Big Data to Understand Human Behaviour (FARE)" - awarded to SPAC's PI Joana Gonçalves de Sá, started in October 2020, is going according to the planned schedule. SPAC successfully applied to an ERC Proof of Concept (FARE_Audit), to complement the main FARE project, and a former research assistant, Íris Damião, applied to and was awarded a competitive FCT PhD fellowship, which started in November 2022.

SPAC currently has around 14 members, including 1 PI, 4 Post-doctoral researchers (supported by FARE and FCT-funded project), 2 PhD students (individual FCT fellowship), 1 Research Assistant, 2 Programmers, 1 Data Manager and 1 Project Manager (half-time), and several MSc and undergraduate students. After a period of significant growth in size during 2020 and 2021, SPAC consolidated its team and reached its maximum size during 2022.

SPAC has also put significant effort into preparing the ground for future research, by establishing and developing new group resources (computational, sharing of information, datasets, etc.) aimed at facilitating collaboration and interaction between group members. SPAC members also got involved in LIP's community and activities, by taking part in the informal "Big Data" group, C4 meetings, LIP seminars, schools and other outreach activities.

Research outputs and Science Communication

The group finished a long-term project on using different datasets to "now-cast" respiratory diseases and minimize their burden to health systems. This work has led to one MSc thesis, three manuscripts (all currently undergoing peer review) and a white paper, co-written with several national experts on disease monitoring, using a One-Health approach.

Several group members had their work accepted in the main conferences in the field. Together, SPAC members gave 6 oral presentations and 5 poster presentations in international conferences during 2022, and Joana Gonçalves de Sá was an invited speaker at 6 seminars or conferences.

SPAC is strongly involved in science communication, outreach and citizen engagement. SPAC members published blog posts aimed at a general audience and participated in different outreach activities. Sara Mesquita co-led the Lisbon Data Visualization Meet-up, Simone Lackner was strongly involved in the SoapBox Science initiative and David Almeida was elected the president of HeforShe Lisbon. Joana Gonçalves de Sá participated in 5 round tables, wrote 2 newspaper opinion articles and gave 5 interviews to the media, both on disinformation and COVID-19 control and was interviewed for two podcasts. SPAC's work received wide media attention, both national and international, and the European Research Council highlighted SPAC's work in a dedicated piece.
Overall, SPAC has accomplished several important goals and is in a very good position to begin 2023, with sufficient funding, three manuscripts under review and another submitted for publication.

Lines of work and objectives for next year

In 2023, SPAC expects to continue establishing itself as a leading research group in complexity and social physics and increasing its national and international standing.

Current research projects include:

A. Digital Epidemiology and Disease Control, by developing new methods and approaches, at the interface between theory, computational and experimental sciences. This research line has been particularly active during 2022, with strong emphasis on research and on supporting the mitigation efforts of the COVID-19 pandemic and other respiratory viruses, and will continue in 2023. These include analysis of both traditional and new datasets (micro-blogging and social media, online searches) to offer improved information systems and close to real-time now-casting.
B. Behaviour and Social Physics, by taking advantage of the so-called Digital Revolution and the large datasets (from social media to health apps) and analytical tools now available. The expectation is that studying the behaviour of large numbers of individuals will enable the emergence of large-scale quantitative social research, from a theoretical and first-principles perspective. Most of the group members will be focusing on this research line in 2023. In particular, the newly awarded ERC-PoC FARE_Audit allows us to expand from social media to search engines and study their impact on the creation of misinformation bubbles.
C. Ethics in Data Science, by developing and testing proof-of concept tools to improve online privacy and raising awareness of the risks of the Digital Revolution. For example, the group has developed a bot system that mimics human browsing behavior and reduces the need for real data, protecting user privacy.

Human Resources:

Following the strong growth of 2021 and early 2022, the goal is to cement the current team and limit new hires to one post-doc (one is outgoing). In parallel, and as most group members are supported by ERC_FARE, there is a medium-term strategy to support PhD holders in applying to individual, competitive fellowships. The expectation is that, in the next four years, all current postdocs will have secured their independent funding and are ready to pursue independent scientific lines.

Research Outlook:

Most effort will be dedicated to:

1. Continuing supporting the respiratory disease-control efforts. This includes ongoing collaborations with the national health authorities in both database creation and analysis;
2. Testing the current pipeline for social media analysis, including users and information networks (with a strong focus on the Twitter platform);
3. Finishing the dataset of "fake news" and other sources of misinformation (currently includes close to 60.000 fact checked items);
4. Finishing and pilot-testing a large-scale, online-based, behavioral survey;
5. Defining strategies for computationally sound and ethical social media analytics, including finishing the "bot auditing system" briefly mentioned above;
6. Strengthening scientific bridges within the group and with the broader LIP community;
7. Improving science communication and outreach, particularly in the area of ethical risks of AI.

Overall, SPAC expects to continue establishing the cornerstones of strongly multidisciplinary quantitative research in social physics and complexity at LIP.

Medium-term (3-5 years) prospects

SPAC intends to internationally cement its position in social physics research and help improve the current national research capacity, mostly through infrastructure creation and postdoctoral training.

The Research at SPAC will focus on understanding properties of spreading on networks (of information, misinformation or pathogenic agents) and human behaviour, from the individual to the societal levels. In a broader way, the development of the field of "Social Physics" will rely strongly on applying theoretical models from physics (ex. diffusion, statistical physics) and simulations (ex. Monte Carlo) to human interactions. Therefore, it is expected that strong collaborations will arise with different LIP research groups. These collaborations can easily expand to international partners, including CERN and others that are strongly growing their DS&AI (data science and artificial inteligence) resources.

The group is fully-funded for the next 3 years and minimal effort will be put on grant writing with two exceptions: supporting senior group members to secure independent funding and participating in international collaborative efforts, both in pandemic and/or misinformation control. During 2023, we expect that 2 postdocs will apply for independent funding, to jointly apply to a COST-Action and to prepare an ERA-Chair application. Applying to a second ERC Proof-of-Concept will also be considered.
Finally, the group accepts its strong social responsibility and, parallel to scientific output, consistent efforts will be developed to improve public understanding of science and of the current risks brought about by the digital revolution.

SWOT Analysis

Strengths

Solid multidisciplinary team; Demonstrated capacity to attract high quality researchers and competitive funding.

Weaknesses

Limited history of collaboration with researchers at LIP or with LIP's main research partners; Limited participation in international networks.

Opportunities

Ongoing research receiving wide (both popular and scientific) interest; Ample space to establish SPAC as a leader in a very novel research field; High interest in future collaborations both inside and outside of LIP.

Threats

Very competitive research areas, particularly misinformation and digital epidemiology.

SPAC

Publications

2 Proposals and related studies

- *"A Vertical System for Ethical Certification of Personal Data Research"*, Paulo Almeida, José Reis and Joana Gonçalves de Sá,
- *"Sistema de monitorização de doenças respiratórias transmissíveis"*, Various authors,

Presentations

8 Oral presentations in international conferences

- Lília Perfeito and Joana Gonçalves-Sá: *"An evolutionary model for the spread of information on Twitter"*, 2022-02-09, NetSciX 2022 - International School and Conference on Network Science, Porto, Portugal
- Cristina Mendonça and André Mata: *"A socio-metacognitive model of pluralistic ignorance: The case of prejudice"*, 2022-05-06, International APPE – SEPEX Meeting, Faro, Portugal
- Joana Gonçalves-Sá: *" Public Law facing the pandemic: the Portuguese context"*, 2022-07-15, Global Meeting on Law & Society: Rage, Reckoning & Remedy, Lisbon, Portugal
- Simone Lackner, Frederico Francisco, Cristina Mendonça, André Mata and Joana Gonçalves-Sá.: *"Some scientific knowledge is a dangerous thing: overconfidence grows non-linearly with knowledge"*, 2022-10-17, CCS 2022 - Conference on Complex Systems, Palma de Maiorca, Spain
- José Reis, Íris Damião and Joana Gonçalves-Sá: *""Doing the Research": Differential Tracking in Disinformation Websites and its Impact on Search Engine Results and Third-Party Content"*, 2022-10-18, CCS 2022 - Conference on Complex Systems, Palma de Maiorca, Spain
- Sara Mesquita, Lilia Perfeito, João Loureiro, Cláudio Haupt-Vieira and Joana Gonçalves-Sá: *"Understanding COVID-19 pandemic trajectories: why changes in online behavior matter for now-casting"*, 2022-10-27, [3C] Cells, Computers & Clinics , Oeiras, Portugal
- Ana Sofia Brás Pinto, Lilia Perfeito, Sara Mesquita, Nuno Pereira and Joana Gonçalves-Sá: *"A method to infer diagnoses from prescription data"*, 2022-10-27, [3C] Cells, Computers & Clinics, Oeiras, Portugal
- Joana Gonçalves-Sá: *"Misinformation/Fake News – what's new? (keynote)"*, 2022-11-28, DATA4CitSciNews: Data Journalism, Misinformation and Citizen Science Event, Barcelona, Spain

5 Poster presentations in international conferences

- Sara Mesquita, Lília Perfeito, João Loureiro and Joana Gonçalves-Sá: *"Understanding COVID-19 pandemic trajectories: why changes in online behavior matter for now-casting "*, 2022-02-10, NetSciX 2022 - International School and Conference on Network Science, Porto, Portugal
- Lília Perfeito and Joana Gonçalves-Sá: *"The microevolution of information on social media"*, 2022-10-20, CCS 2022 - Conference on Complex Systems, Palma de Maiorca, Spain
- Eleonora Tulumello, Sara Mesquita, Lilia Perfeito, Irma Varela-Lasheras and Joana Gonçalves-Sá: *"Flu or Not: A computational approach to respiratory-disease surveillance before and after COVID-19"*, 2022-10-20, CCS 2022 - Conference on Complex Systems, Palma de Maiorca, Spain
- Irma Varela-Lasheras, Eleonora Tulumello, Sara Mesquita, Joao Oliveira, Lília Perfeito and Joana Gonçalves-Sá: *"Flu or Not: A computational approach to respiratory-disease before and after COVID-19"*, 2022-10-26, [3C] Cells, Computers & Clinics , Oeiras, Portugal
- Irma Varela-Lasheras, Sara Mesquita, Eleonora Tulumello, Lília Perfeito, and Joana Gonçalves-Sá: *"Flu or Not: A computational approach to respiratory-disease before and after COVID-19"*, 2022-11-09, EPH - 15th European Public Health Conference 2022, Berlin, Germany

2 Oral presentations in national or international meetings

- Joana Gonçalves-Sá: *"Social Physics and Complexity"*, 2022-07-08, Jornadas LIP 2022, Coimbra
- Joana Gonçalves-Sá: *" Identifying and Predicting Emergency Admissions"*, 2022-11-28, INCoDe.2030: Artificial Intelligence Workshop, Lisbon, Portugal

2 Presentations in national conferences

- Cristina Mendonça e André Mata: *"Ignorância pluralística sobre preconceito (a parte do racismo e dos bolos)"*, 2022-06-21, XI Simpósio Nacional de Investigação em Psicologia, Vila Real, Portugal
- Joana Gonçalves-Sá: *"Fake News (keynote)"*, 2022-10-27, 22º Congresso Nacional de Pediatria, Porto, Portugal

5 Oral presentations in advanced training events

- Sara Mesquita: *"Visualização de dados em Saúde Pública"*, 2022-03-10, Tele-health, Integrated Master Degree in Medicine, NOVA Medical School, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Data Science (and Digital Epidemiology) in Public Health"*, 2022-06-22, Disciplina de Sistemas de Informação, Escola Nacional de Saúde Pública, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Risks and Ethics in Data Science"*, 2022-06-30, Data Science School in (Astro)Particle Physics and Cosmology, University of Coimbra, Portugal
- Joana Gonçalves-Sá: *"Social Physics"*, 2022-07-12, LIP Internship Programme Tutorial Week 2022, LIP, Lisbon, Portugal
- Joana Gonçalves-Sá: *"The future of Complex Systems Science (roundtable)"*, 2022-11-25, 2022 PhDCS Doctoral Workshop: The future of Complex Systems Science, ISCTE, Lisbon, Portugal

2 Student presentations in advanced training events

- Sara Mesquita: *"Early online behavior during pandemics: why it matters for now-casting"*, 2022-07-04, COSMOS Konstanz - The Computational Summer school on Modeling Social and collective behavior, Konstanz, Germany
- Armando Gonçalves: *"Using Big Data to Study Geographical Variation in Antibiotic Prescription"*, 2022-09-09, LIP Internship 2022 - Final Workshop, LIP, Lisbon, Portugal

3 Seminars

- Joana Gonçalves-Sá: *"Why do we believe in misinformation?"*, 2022-03-11, Computer Science Seminar Series, College of Engineering, Mathematics and Physical

Sciences, University of Exeter, online/Exeter, UK

- Joana Gonçalves-Sá: *"Física Social e Complexidade"*, 2022-09-15, 4ª Conferência de Física dos Países de Língua Portuguesa: A Física para o Desenvolvimento Sustentável, online/Praia, Cape Verde
- Joana Gonçalves-Sá: *"Futuros sistemas de vigilância de doenças emergentes"*, 2022-11-03, One Health, Uma Só Saúde - Forças, desafios e oportunidades de melhorar a articulação intersetorial, Faculdade de Medicina Veterinária, UL, Lisbon, Portugal

11 Outreach seminars

- Joana Gonçalves-Sá: *"A multiplicação das atividades. Como potenciar a Investigação na carreira de Docente Universitário? Como conciliar com outras atividades? (roundtable)"*, 2022-02-04, Research in Higher Education: How and What for?, online/Coimbra, Portugal
- Joana Gonçalves-Sá: *"Sistema de monitorização de doenças respiratórias transmissíveis"*, 2022-02-17, Apresentação Pública: Sistema de monitorização de doenças respiratórias transmissíveis, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Made by Women: I&D e Liderança"*, 2022-03-08, Women Create Value, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Impacto na Decisão e na Sociedade (roundtable)"*, 2022-04-18, Sondagens: da Conceção ao Impacto, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Communication in Science: are we living in a misinformation era?"*, 2022-04-21, 12th ITQB NOVA PhD Students' Meeting, Oeiras, Portugal
- Joana Gonçalves-Sá: *"Experiências com ERC (roundtable)"*, 2022-04-29, DEI-Day, Departamento de Engenharia Informática, IST, UL, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Why do we believe in Disinformation?"*, 2022-05-16, Como Dialogar com quem não quer ouvir: para lá da polarização e da desinformação, Lisbon, Portugal
- SPAC: *"Inteligência Artificial (roundtable)"*, 2022-06-22, Encontros Com Impacto, Lisbon, Portugal
- Joana Gonçalves-Sá: *"A Revolução Digital e os Dados: como influenciam as nossas vidas?"*, 2022-09-09, Academia Socialista, Leiria, Portugal
- Joana Gonçalves-Sá: *"How do we know what we know?"*, 2022-10-14, ATLAS week - Universal Science: Curiosity, Diversity, Discovery, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Mulheres nas TIC: Compromisso em Ação (roundtable)"*, 2022-12-14, 2º Encontro Aliança para a Igualdade nas TIC, Lisbon, Portugal

12 Articles in the media

- *"Porque tantos deixaram de confiar na ciência? O que pode fazer o Big Data por nós?"*, Daniel Oliveira, interview with Joana G Sá., Perguntar Não Ofende (podcast)
- *"PS e a esquerda: O divórcio já tem dois anos"*, Nuno Aguiar, piece about SPAC's research and interview with Joana G Sá., Visão
- *"Ensinar ou não ensinar, eis a questão"*, Joana Gonçalves-Sá, Público
- *"Conselho Europeu de Investigação financia combate à desinformação"*, André Amaral and Lusa, article about FARE_Audit, Expresso das Ilhas
- *"Bolsas para Portugal para preservar terapias celulares e rebentar bolhas de desinformação"*, Teresa Sofia Serafim, article about FARE_Audit, Público
- *"Conselho Europeu de Investigação atribui financiamento a projecto sobre desinformação"*, Agência Lusa, article about FARE_Audit, Diário de Notícias
- *"Algoritmos: Espaço Público"*, Documentary including interview with Joana Gonçalves de Sá, RTP3
- *"Mais ciência, melhores empresas"*, Joana Gonçalves-Sá, Público
- *"O destino de uma epidemia"*, Hugo Séneca, article about SPAC's proposal for a monitoring system for transmissible respiratory diseases, Expresso
- *"Comunicação de Ciência e BIG DATA"*, The Science Communication Network, interview with Joana G Sá, The Science Communication Network Podcast
- *"Joana Gonçalves de Sá: Por que motivo são partilhadas fake news?"*, Interview with Joana G Sá about FARE project, Jornal Médico
- *"Luis Enrique y la novedad en el efecto Dunning-Kruger"*, Jesús Méndez, article about FARE, Heraldo de Aragón

Organized Events

1 National Conferences or Workshops

- *"Sistema de Controlo de Doenças Infecciosas Respiratórias - Workshop"*, [Conf-WS-Nat] 2022-06-02 / 2022-06-03, Nova SBE, Cascais, Portugal

1 Outreach Event

- *"Apresentação Pública: Sistema de monitorização de doenças respiratórias transmissíveis"*, [OutR] 2022-11-17, Reitoria da Universidade Nova de Lisboa, Lisbon, Portugal

Theses

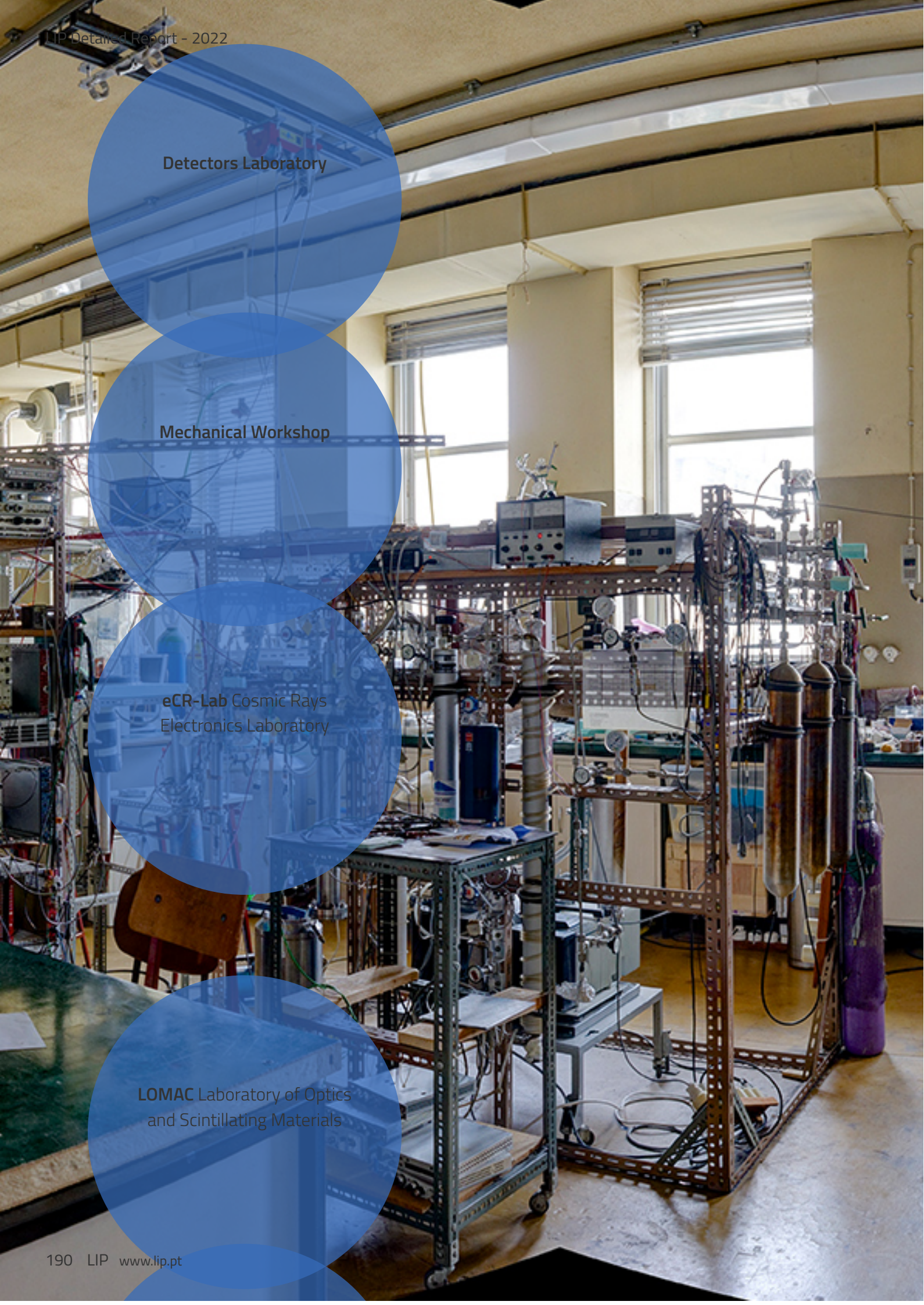
2 PhD

- Sara Mesquita: *"Using online behaviour to track global outbreaks and pandemics"*, 2020-09-01 , (ongoing), UNL, Supervisor(s): Joana Gonçalves-Sá
- Íris Damião: *"Differential tracking on disinformation websites and its impact on search engine results"*, 2022-11-01 , (ongoing), IST, Supervisor(s): Joana Gonçalves-Sá

1 Master

- David Almeida: *"PandeMedia: an annotated corpus of digital media for issue salience"*, 2020-09-14 / 2022-11-23, (finished), FCUL, Supervisor(s): Joana Gonçalves-Sá

RESEARCH Facilities


Detectors Laboratory
Mechanical Workshop
eCR-Lab Cosmic Rays Electronics Laboratory
LOMAC Laboratory of Optics and Scintillating Materials

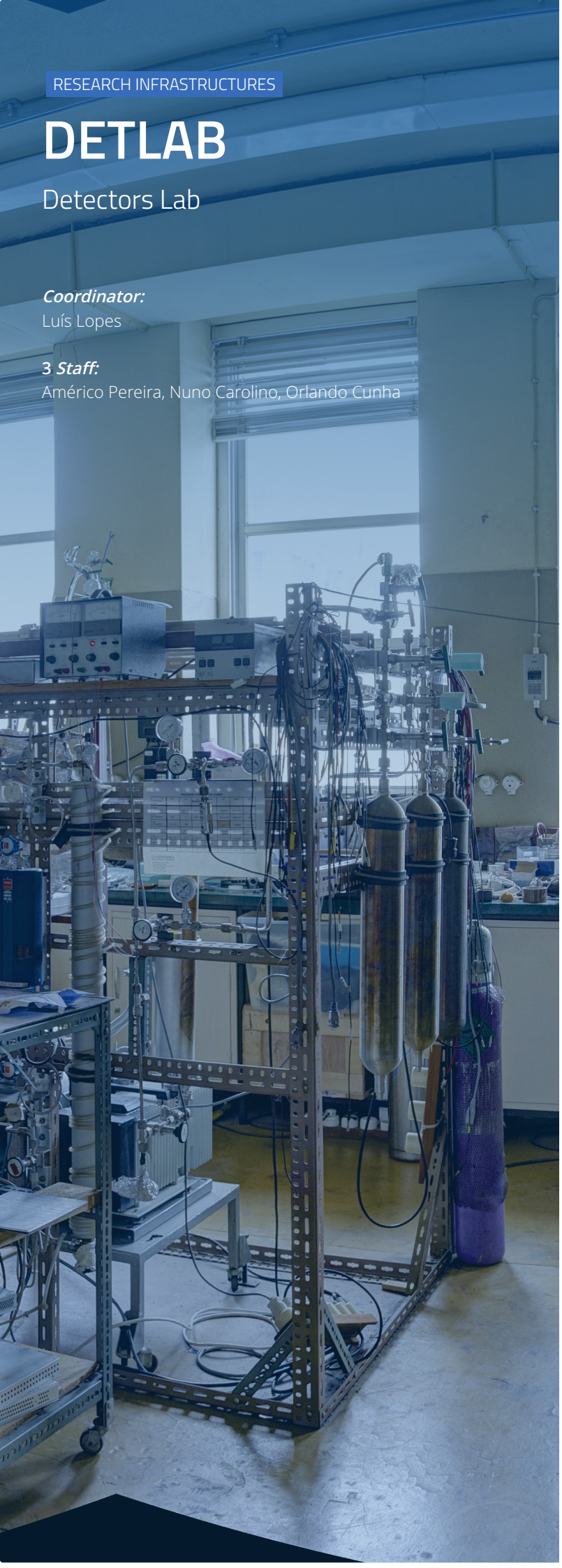
RESEARCH INFRASTRUCTURES

DETLAB

Detectors Lab

Coordinator:
Luís Lopes

3 *Staff:*
Américo Pereira, Nuno Carolino, Orlando Cunha



Executive summary

LIP's Detectors Laboratory (DL) performs R&D and production of a wide variety of detectors and associated systems for the collaborations and projects in which LIP is involved, continuously supports the LIP groups in their R&D activities, and provides products and services to external entities. The contribution of the DL spans from project design to the installation and maintenance, following a procedure similar to industry's. As in the previous years, the DL managed to keep all its internal commitments and increase the number and magnitude of the services for external entities.

The main activities in 2022 concerned the R&D and production of different types of large area Resistive Plate Chambers (RPCs) used in experiments and projects in which LIP is involved, and the support to the LIP groups in their R&D activities. There were also contracts with external institutions. We were able to give an adequate response to all the requests from internal and external groups, despite the absence of one collaborator since September 2021.

DetLab

Overview

LIP's Detectors Laboratory (DL) is currently split into two different facilities:

F1 is where the research groups develop their work and where all electronics projects are developed. Situated in the fourth floor of the Physics Department of the University of Coimbra (UC), it is equipped with most of instrumentation and tools needed in a detectors research lab. Each group has an independent work area to assemble setups and develop their activities. The work related to R&D and production of electronics is performed here. Two secure rooms are available, one for gas bottles and another for radiation sources.

F2 is where the R&D and production of large area detectors takes place. Situated in the ground floor of the Physics Department of UC, this area has been set up during the last years and is equipped with most essential instruments and tools in adequate quantity and quality. Currently available are a medium clean room for the assembly of the sensitive parts of the detectors, a room for painting and a large area for detector integration and test.

Assessment of the past year: objectives vs. achievements

LIP's DL was able to fulfill most of the objectives scheduled for 2022. Most of them were achieved in close collaboration with the Mechanical Workshop (MW), taking advantage of having now a common management. The main ones were: RPC Neutron Detector for the nDet group. Systems for extracellular measurements for the Bioelectronics & Bioenergy Research Lab of UC (external entity), and many other small gadgets for the same group and for the UC Biophysics group. Many other R&D groups manly from UC but also from other universities and research centers asked for our collaboration. This included only production in some cases, but also R&D in others.

A fundamental role of the DL is the continuous support it provides to all LIP groups performing R&D activities. In 2022 the DL contributed with technical work and added value to the following projects: HiRezBrainPET, DUNE, HADES, SCORE (NUC-RIA), STRATOS, CCMC/Cloud Chambers, Gaseous Detectors, ImprovePT, CCMC/ECOTOP, Dark Matter, RD51, nDet, AUGER, ATLAS, RPC-ADVANCE, RPC-INOVA, Dosimetry, LouMu, ECO-Outreach and SND. Besides detector work, this included the layout, loading and testing of in-house developed electronic boards.

The work on sealed RPC has finally start in close collaboration with the RPC R&D Group.

We started a collaboration with a South Korean research group to develop and build timing RPCs.

The call for the installation of a Clean Room ISO 6 was open.

Direct contracts for the provision of services and products by the DL to external clients amounted to 10% of our human-power and returned over 7.5 k€ (around 7.5% of the annual staff cost). There were no significant delays in any of the submitted requests from LIP groups.

Lines of work and objectives for next year

We hope to install the ISO 6 Clean Chamber and open the possibility to develop and construct different kinds of detectors and instruments. This goal is transported again from last year.

The DL will achieve the construction of the first large area muon telescope with sealed RPC's. This is a major development, even more in the context of global warming issues and regulations.

Already started is the production of Spark Chambers for outreach purposes. In addition, we plan to produce: HV power supplies; gas monitoring and/or control systems; boards for charge and time measurements. The instruments for the projects ImprovePT, ATLAS, DUNE and MINGO (small RPC muon telescopes) will consume a considerable fraction of our time.

Concerning the support to LIP groups, the DL is expected to contribute in the construction, assembly and test of the following projects and/or setups: HiRezBrainPET, DUNE, HADES, SCORE (NUC-RIA), STRATOS, CCMC/Cloud Chambers, Gaseous Detectors, ImprovePT, CCMC/ECOTOP, Dark Matter, RD51, nDet, AUGER, ATLAS, RPC-INOVA, Dosimetry, LouMu, NUC-RIA, ECO-Outreach and SND. We also plan to maintain or increase the weight of the work contracts with external groups. We expect to produce and sell two LIP spark chambers for outreach purposes.

The DL&MW, together with the Bioelectronics & Bioenergy Research Lab of UC will submit a patent for a Smart multi-gas incubator for portable low-noise electrophysiology.

Overall, the goal of the DL is, each year, to give an important contribution to LIP's research, working in an organized and efficient way with all our internal and external collaborators.

Medium-term (3-5 years) prospects

In the medium-term we expected to be even better prepared to answer positively to all the requests of the LIP research groups, which is our main task. In this way we will also be able meet the requirements of external clients.

We expect to achieve in the next 4-5 years a minimum of 20 k€ per year in direct contracts, without affecting the support to the LIP research groups. We are prepared to increase our staff if needed, in order to give a proper answer to all demands.

We already started, and will continue, R&D and production of new products for outreach. Nevertheless we already had some contacts and good indications for the delivery of three LIP spark chambers.

The shared coordination between DL and MW is of major importance to achieve this objective since it allows for better programing and a largely increased number of available services and products.

We hope to continue to upgrade our capabilities and skills, working close to other DLs around the world (mostly in Europe) to better understand where we can make a difference and take maximal advantage from our expertise. More precise plans for the medium and long term are difficult to outline since, as we are a support infrastructure and must follow the needs and options of the research groups.

SWOT Analysis

Strengths

Our well equipped lab and multidisciplinary and motivated team able to give a satisfactory answer to most requests.
The possibility to travel to the places where our hardware is located allows for continuous monitoring, from the R&D phase to the installation, operation and maintenance of most of the systems we developed and built.
This close monitoring allows for constant learning and improvement of our knowledge and skills.
The possibility to programing the work in advance.

Weaknesses

Our premises impose serious limitations on efficiency and production capacity: space is limited and the time needed to performed any required changes is huge, sometimes unacceptable.
One collaborator with health problems is absent from work for long time periods.
There is some inefficiency (waste of time) due to bad preparation of the work when our collaborators/clients do not consult the DL experts in advance. There was a significant improvements over the past years but we can and should continue to improve.

Opportunities

The confirmed ruggedness and performance of some of our detectors has been opening novel markets. In some cases, we have joined new projects and collaborations as a result of this. In the area of medical instrumentation, the quality of our work is also recognized, thus opening another field to be explored. Products aimed at science outreach, such as the LIP Spark Chamber and the LIP Cloud Chamber, may also play an important role in spreading our name/brand. New instruments should be considered.
In the collaborations we belong to, updates and construction of new detectors are opportunities that we must consider, in the medium and long term. New collaboration opportunities are also being explored, namely within international organizations, in order to extend our lines of action and/or the implementation of the products already developed.

Threats

The uncertainty in some of our funding sources in the medium and long term.

RESEARCH INFRASTRUCTURES

WORKSHOP

Mechanical Workshop

Coordinator:
Luís Lopes

4 Staff:
Carlos Silva, Jorge Moreira, Nuno Filipe Silva Dias, Rui Alves

Executive summary

The Mechanical Workshop (MW) of LIP was established in 1986 to support the experimental activities to be performed in collaboration with CERN. At present, the available equipment and staff (one technician and three engineers) allows for the MW to perform a large spectrum of mechanical services, from project to production and testing. Today, the MW provides services not only to research groups, inside and outside LIP, but also to external companies.

Three decades of experience make very clear that, without the MW, it would not have been possible for LIP to accomplish at the same high-quality level all its achievements in detector R&D, or all its responsibilities in international collaborations (CP-LEAR, DELPHI, HERA-B, ATLAS, HADES, Auger, SNO+, etc.). Equally evident are the benefits to the R&D community, at local and national level.

The experience acquired over the last decades should not be take as guarantee for the future, but as a reason to improve the performance for a continued and sustained growth.

Workshop

Overview

LIP's Mechanical Workshop is well prepared in terms of both equipment and specialized human resources. There is a number of modern CNC machines that allow for complex jobs to be performed. The ability to contribute to all requests from the beginning, including the mechanical project design, allows for a faster response to the needs. In this way, we are able to start preparing the production at an early stage, which contributes to an optimized execution of each job.

Assessment of the past year: objectives vs. achievements

The MW was able to fulfill most of the objectives scheduled for 2022, often in close collaboration with the Detectors Laboratory (DL), taking advantage of common management. The main projects were: protoDune TPC, SND Frames, RD51, Cloud Chamber, Dosimetry. All these were completed respecting the pre-defined delivery times.

As for the DL, other projects included: RPC Neutron Detector for the nDet group. Systems for extracellular measurements for the Bioelectronics & Bioenergy Research Lab of UC (external entity), and many other small gadgets for the same group and for the UC Biophysics group. Many other R&D groups manly from UC but also from other universities and research centers asked for our collaboration. This included only production in some cases, but also R&D in others..

Along the year, unexpected new projects (medium size) arised and we were able to cope with all of them. Namely: three more frames for SND, mechanical parts for the CERN-Workshop, two cloud chambers (only one was planned). A large number of "small" requests from LIP groups were also received, including design, production and test.

We significantly increase the number of external clients, especially among universities and national research centers, which should be our main field of action. This line consumed around 40% of our human resources and returned profits of 12.5 k€. Some of our 2022 clients were: CNC-Centro de Neurociências e Biologia Celular, ITAV-Instituto do Ambiente, Tecnologia e Vida, SerQ-Centro de Inovação e Competências da Floresta, IT-Instituto de Telecomunicações, UC-Biotech, Bioelectronics & Bioenergy Research Lab, ICNAS-Produção, Biophysics group, LIBPhysGian, FireLab, and many more.

To achieve this performance level it is important to bear in mind that some tasks should be outsourced, in order to spare time and resources for the team to focus where their expertise is really necessary. Also the shared coordination of the DL and MW was of fundamental importance for achieving this performance.

Lines of work and objectives for next year

The upgrade of the HiRezBrainPET (if funded) is the largest project already scheduled for 2023. Some other medium size projects are also schedule, like four MINGO muon telescopes, the spare module for the HADES-FD and three more frames for SND.

In addition, a considerable number of small (one week or less) requests are schedule.

The DL&MW, together with the Bioelectronics & Bioenergy Research Lab of UC will submit a patent for a Smart multi-gas incubator for portable low-noise electrophysiology.

The improvement of the work space will also consume some time.

External collaborations are of primary importance and we should be able to maintain the number of requests from the past year or even increase. Opening the Infrastructure to new markets, other than research centers and universities, should be carefully consider as an option when the number of internal demands does not spend all the available human resources.

Medium-term (3-5 years) prospects

Beside the continuous work for the LIP research projects and external groups/companies, in the next years we plan to consolidate/improve the MW:

We plan to unify the software tools used in design and production. The use of different tools leads to many small but intricate problems. In this line, we will connect the old CNC machines to our CAM software, which will improve performance. This is actually work in progress.

We will also search for new collaborations, preferentially within the academy and research communities. In addition, the local market should be explored as a source of work to fill some time gaps and increase profits.

SWOT Analysis

Strengths and Opportunities

The valuable know-how, experience and skills of our staff.

The possibility to easily extend our services to other research centers and companies.

The new capabilities brought in by the new large-area CNC machine.

Communication within the group is improving with time.

Weakness and Threats

Space organization needs to be improved, and this was partially achieved over the last year.

Many old machines and tools no longer used need to be sent out (this is close almost solved).

There is the need for better communication within the group, especially between all the parts involved in a project, in order to improve performance and reduce mistakes.

The coordinator must continue to improve his knowledge in some important areas, manly on the capabilities of each machine, in order to be able to plan towards more efficient global group performance.

RESEARCH INFRASTRUCTURES

E-CRLAB

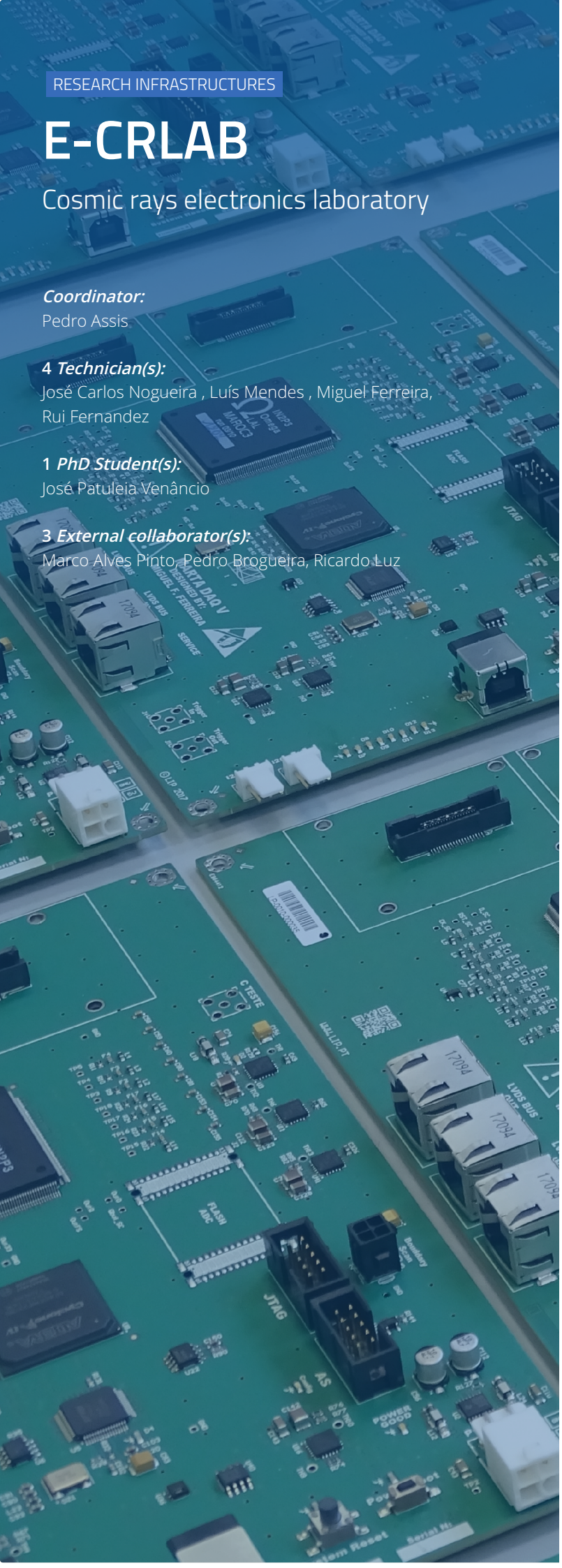
Cosmic rays electronics laboratory

Coordinator:
Pedro Assis

4 *Technician(s):*
José Carlos Nogueira , Luís Mendes , Miguel Ferreira, Rui Fernandez

1 *PhD Student(s):*
José Patuleia Venâncio

3 *External collaborator(s):*
Marco Alves Pinto, Pedro Brogueira, Ricardo Luz



Executive summary

The e-CRLab is mainly dedicated to the development of electronics for particle and astroparticle physics experiments. The focus is put on fast digital electronics implemented in FPGAs and on front-end electronics. The laboratory has the capability to design complex printed circuit boards and to produce simple printed circuit board (PCB) prototypes. The production and assembly of complex PCB is outsourced. There is also the capability to do rework in PCB boards. A small set of mechanical tools allows the production of simple detector prototypes mainly for proofs of concept. In 2022 the e-CRLab had two main activities: the development, test and commissioning of the electronics for the MARTA detector and the development and test of electronics for the ATLAS upgrade.

MARTA is an RPC-based R&D project within the Portuguese participation in the Pierre Auger Observatory. The electronics were developed at the e-CRLab that has the responsibility of its operation. The systems are expected to become online during 2023. Hodoscopes were also developed and are crucial as calibration- and test-bench of the other detectors used in Auger.

The eCRLab is deeply involved in the HGTD electronics in the context of the ATLAS upgrade - namely testing the front-end electronics for fast timing and, and also in the development of auxiliary systems such as DCS and interlock.

The e-CRLab is also involved in outreach and teaching and gives support to several LIP groups (consulting and design review).

e-CRLab

Overview

The e-CRLab was created as a laboratory for the development of DAQ systems for cosmic ray experiments but has in the recent years diversified its activities. Nowadays, the e-CRLab is mainly dedicated to the development of electronics for particle and astroparticle physics experiments. The focus is put on fast digital electronics implemented in FPGAs and on front-end electronics. The laboratory has the capability to design complex printed circuit boards and to produce simple printed circuit board (PCB) prototypes. The production and assembly of complex PCB is outsourced. There is also capability to do rework in PCB boards. A small set of mechanical tools allows the production of simple detector prototypes mainly for proofs of concept. The laboratory facilities are located at LIP-Lisboa and are composed by an office room, one instrumentation room with state-of-the-art equipment, and instrumentation rooms dedicated to the development and testing of the different setups. A small mechanical workshop for detector prototypes development and a dark room are also available. The laboratory counts with four electronics technicians, has the support of several researchers and has PhD and Master students involved in its activities.

Assessment of the past year: objectives vs. achievements

During 2022, the laboratory has been involved mainly in the MARTA R&D project for the Pierre Auger Observatory, and in the development of electronics for the ATLAS upgrade. Support has been given to several groups at LIP.

In MARTA it was finally possible to organize campaigns in Argentina to commission the setups: a hodoscope for precision studies of the response of the Auger main detectors to isolated muons, whose firmware and software are being finalized and tested; and the "Peter Mazur" station, a regular detector station of the Auger array equipped with RPCs underneath. Recent changes to the setup allow for the estimation of the stability of the RPC efficiency. Most hardware has been deployed and the interface between MARTA and the water Cherenkov detector is being set up in coordination with the AMIGA team (owner of support infrastructure). Both setups are being tested and finalized and are expected to become online in the first quarter of 2023.

The second main activity is related to the ATLAS upgrade and to the in-kind contribution to this program. The laboratory is performing work for the HGTD detector, with the testing program of the ALTIROC ASIC. A technician hired by ATLAS is in the e-CRLab to give support to these activities. During the last year it was possible to acquire expertise in the testing of the ASIC with impressive progress. Moreover, the laboratory has given support to the design of auxiliary systems such as the high voltage power supply for the TileCal, the DCS of the HGTD system and the Interlock system.

Activities within medical applications are being pursued by giving support and adapting solution for the readout of sensors, leaning on the acquired expertise.

It has not yet been possible to dedicate resources to the instrumentation of silicon-based sensors. However, support is being given to the operation of such sensors installed on space radiation monitors. This activity is developed within the Space Radiation group.

Important developments were also made in the slow control and monitoring of the MARTA project. This development comprises the automation of the data filling mechanism into a database, coupled to an off-the-shelf tool for visualization of the data with web interface. Such system has also been deployed in the tomography system at the Lousal mine.

The laboratory has also given support to different groups developing electronics. Most activity has taken the form of consulting, design review or development of small projects. Support has also been given to outreach activities.

Lines of work and objectives for next year

During this year, it is expected that the setups within the Pierre Auger Observatory reach a maturity level and start acquiring data in a stable way. Once the nominal operation at low gas flux is achieved on the field and the performance of the setups is assessed, upgrades to the setup can be considered. Such upgrades are to be driven by the Auger group exploiting the installed setups.

Within the ATLAS activities, the main development is related to the testing of the ALTIROC ASIC. We plan to participate on the tests of the new version (V3). We are currently negotiating our contribution. It is expected that a significant contribution related to the radiation hardness assurance can be achieved. Moreover, we would like to be able to perform tests with the sensor coupled to the ASIC. We will also try to establish synergies with groups using the same type of sensors. The development of auxiliary systems for the ATLAS upgrade will continue. Contributions are expected to be given in the DCS and Interlock subsystems. These activities are done in close cooperation with the LIP ATLAS group.

In terms of DAQ development, we plan to finalize the first parts of the MARTA DAQ upgrade: The development of the multipurpose intelligent module. This will allow the acquisition systems to be more reliable and autonomous. This part can also be deployed in other DAQ or slow control/monitoring systems.

We also plan to increase the support of the laboratory to the LIP community. Such support is expected to be given in consulting or through the development of small electronics projects. One of the novelties is the creation of the first mini-school in electronics to give training in basic electronics design to the community. One important aspect is the training of the new students that are involved in such activities.

Finally we will pursue the development of instrumentation for medical devices taking advantage of the know-how existing in the laboratory. We expect to be able to produce data acquisition systems for SiPM sensors and also for Si-based detectors.

Medium-term (3-5 years) prospects

The infrastructure plans to secure the acquired competence in front-end DAQ and in digital electronics as well as in the system integration. The systems developed will be brought to a mature level and we will exploit possible uses, seeking internal and external partnerships.

We will continue pursuing synergies with research groups at LIP to apply and develop the competences acquired and to support the activities whenever necessary. One of the main lines of development of the infrastructure is based on the capability to develop faster systems with better time resolutions and higher bandwidths. The collaboration with the ATLAS group will be reinforced with the test and developments on the front-end electronics for fast systems.

SWOT Analysis

Strengths

Competences acquired in digital logic design as well as the competence in the design of complex electronic systems. Competence in handling several types of detectors such as RPCs, scintillators coupled to photomultipliers and silicon photomultipliers. Activities developed in the context of research projects. Capability to develop characterization systems. Possibility to plan and perform irradiation campaigns.

Weaknesses

The current level of funding is not compatible with the full development of detectors. Up to now it was not possible to attract direct funding for detector development. Independetly publishing the work developed has been systematically delayed and must be pursued.

Opportunities

R&D activities in the framework of MARTA, SWGO and muon tomography projects create opportunities to lead R&D project and to consolidate the existing core lab activities.In the long term, ATLAS offer the opportunity to consolidate activities on fast and digital electronics. The radiation damage studies present the possibility to attract students and financing through the SpaceRad group. Training activities and master theses developed in e-CRLab may allow to increase manpower and to pursue different projects. The know-how acquired can also boost the participation in new projects related with fast timing and the development of instrumentation for medical physics. The investment plan resulting from the FCT evaluation allows for the increase the capability in test-and-measure.

Threats

Financing is always a key issue when developing hardware. Lack of human resources could be an issue in the mid-term.

RESEARCH INFRASTRUCTURES

LOMAC

Laboratory of optics and scintillating materials

Coordinator:
Agostinho Gomes

4 Researcher(s):
Amélia Maio, João Gentil, Ricardo Gonçalo, Rute Pedro

2 Technician(s):
Luís Gurriana, Luís Seabra

2 PhD Student(s):
Beatriz Pinheiro Pereira, Rudnei Machado

3 Undergraduated Student(s) and Trainee(s):
Christian Tanga, Pedro Mendes, Rui Ferreira

2 External collaborator(s):
António Pontes, José Covas

Executive summary

LOMaC is a facility with expertise centered on the preparation and characterization of plastic WLS and scintillating optical fibres, scintillator plates, and related devices to be used in high energy and nuclear physics applications. The activities developed at LOMaC are currently centered on the HL-LHC upgrades, development of materials for next generation of detectors (FCC and others) and the applications to microdosimetry. LOMaC has broad and frequent collaborations with other LIP infrastructures, namely e-CRLab, Detectors Lab, Mechanical Workshop and Computing infrasctrctures.

Research of new scintillating materials for future detectors based on PEN (Polyethylene Naphthalate) and PET (Polyethylene Terephthalate) is ongoing in collaboration with the Institute for Polymers and Composites of the University of Minho (IPC/UMinho) and in the context of the DLight Project and of the LIP FCC group. Small scintillator plates have been produced by injection moulding technique and tests showed promising light yield and transparency. This exploratory R&D project will be one of our main contributions to the implementation of the ECFA Detector R&D Roadmap in the field of calorimetry. Besides, we are currently working in close collaboration with the CERN team in the simulation of a new calorimeter design and towards the construction of a small prototype in the near future.

We complement this development with the study of the radiation hardness of scintillators in real conditions, using data from the TileCal calorimeter of ATLAS. This allow us not only to estimate the expected light yield of the TileCal scintillators at the HL-LHC phase, but will also be an important input for future collider experiments. In addition, the tests of the high voltage distribution boards for the Phase II upgrade of the ATLAS detector are done also at LOMaC.

On the dosimetry side, we are developing a prototype of a dosimeter with sub-millimetric resolution in collaboration with the LIP Dosimetry group.

Since the majority of LOMaC equipments were installed 20-30 years ago and suffered several relocations along the years, maintenance, upgrade and reequipment have been in our priorities in recent years, after the lab settled in the ULisboa building to where LIP moved in 2017. Major interventions in the building have been in the origin of frequent dust clouds and power cuts interfering negatively with our equipments. Parallel work on maintenance and upgrades of LOMaC equipment is expected to continue in a continuous reequipment of the laboratory.

LOMaC

Overview

LOMaC was created for the test and preparation of WLS fibres for the ATLAS TileCal project in the 1990s, with human resources and expertise from CFNUL, LIP, FCUL, and UNL. The entire WLS fibres set for the ATLAS TileCal has been polished, aluminized and quality controlled at LOMaC.

LOMaC's expertise is centered on the preparation and test of plastic WLS and scintillating optical fibres, scintillator plates, and related devices to be used in high energy and nuclear physics detectors. The LOMaC facilities and setups are the following:

- Facility to cut/polish bundles of optical fibres.
- Optical fibre aluminization facility (by magnetron sputtering).
- Fibremeter – an automated device to characterize sets of up to 32 optical fibres.
- Mono-fibremeter – an automated device to characterize individual optical fibres.
- Tilemeter – an automated device to characterize scintillators.
- PMT test device – automated test bench for the characterization of PMTs.
- Equipment to measure absolute light yield.

LOMaC selected and/or prepared the following sets and types of optical fibres, in chronological order:

- R&D of scintillating and WLS fibres and scintillators for ATLAS.
- WLS fibres for the DELPHI STIC luminosity monitor.
- WLS fibres for the ATLAS TileCal.
- Scintillating fibres for the ATLAS ALFA luminosity monitor.
- R&D for future calorimetry (DREAM project).
- Clear fibres for the SNO+ calibration system.
- WLS fibres for the W104/Icarus muon tagger.
- WLS fibres for the ATLAS TileCal gap/crack scintillators and MBTS upgrade.
- WLS fibres for NEXT prototypes.

LOMaC also studied the light output and uniformity of scintillators for TileCal, having designed the optical masks to improve their uniformity, and tested a set of PMTs also for TileCal. It also gave crucial support to the development of the plastic profiles that house the WLS fibres in the TileCal calorimeter. Preliminary studies in light collection and coupling, as well as scintillator geometry for an FCC TileCal-like detector, were made more recently.

With the end of CFNUL, LOMaC was forced to abandon the building where it was hosted and was set up at FCUL in 2016. LIP moved to the building of the University of Lisbon in 2017 and, since then, we reassembled most of the equipment there.

Currently, most of the LOMaC activities are related to ATLAS Upgrades and the Dosimetry group, expanding now in the direction of the Future Circular Collider detectors.

Assessment of the past year: objectives vs. achievements

During 2022 LOMaC achieved most of the objectives, even if we experienced long waiting times in the delivery of purchased equipments. Part of the projected facilities reequipment is still in progress. We invested in the upgrade of some of the systems and started developing new instruments that will increment the laboratory capability:

- The tilemeter used for the characterization of plastic scintillators was improved with new photosensors, namely a new PMT, and the system was re-commissioned, including the determination of its intrinsic precision.
- A new hodoscope setup for the measurement of the number of photoelectrons in small scintillator plates was started in a dedicated dark room. It consists of SiPMs for the readout of the test sample and the scintillating optical fibres in coincidence. The signal acquisition system including the coincidence trigger generator was assembled, tested and debugged with a controlled signal source (UV LED).
- In the framework of the DLight project, several samples of PEN and PET scintillators were produced at IPC/UMinho and characterized at LOMaC.
- The first trials consisted of micro-extrusion of very small samples, enough to notice scintillation and to determine the polymer's processing parameters (such as temperature, pressure).
- Later a first set of 2 mm thick samples was produced by injection moulding. Measurements of light response and emission spectra were performed at LOMaC.

- A second set of samples with better homogeneity and transparency was produced after a better polishing of the mould.
- The PEN and PET samples were characterised at the tilemeter, comparing their light response with a reference scintillator tile of considerably larger dimension. The PEN samples produced substantial light output with good transmission. More quantitive evaluation requires the simulation of the whole setup in order to be able to take into account the geometrical effects when comparing the light output. The simulation is currently ongoing. The PET samples give much smaller light output, as expected.
- Producing and testing thicker and larger samples with combinations of the materials will be the next step.
- A portable system composed of a UV LED source, dedicated mechanics, and a SiPM photosensor was designed and assembled for the on-site monitoring of samples produced at IPC/UMinho. The goal is to tune the injection moulding parameters to obtain the optimal sample light output.

For the ATLAS Phase-II upgrade, LOMaC is deeply involved in the development of the new TileCal HV system and in aging studies of TileCal optics focusing on scintillators and fibres:

- The long HV development programme was continued during 2022, with new HV boards and cable prototypes tested in LOMaC.
- The monitoring of the light yield of the TileCal scintillators and fibres with Run 2 was finished and the results are being published. A model of the light response degradation with radiation exposure was obtained, including studies of dose rate effects. This allowed to perform extrapolations for HL-LHC scenarios and collect inputs on the radiation hardness of scintillator based detectors with in-situ operation conditions.

Towards more involvement in the ECFA Detector R&D Roadmap implementation, a new activity consisting on simulation studies of a TileCal-like calorimeter for the FCC-ee was initiated in collaboration with a CERN team:

- Adapted an existing FCC-hh hadronic calorimeter. simulation for the FCC-ee specifications.
- Conducted initial studies of the sampling fraction of a scintillator/steel calorimeter using an electron source generator.
- Studied the energy resolution with simulated charged pion beams for a number of geometries with varied granularity.

LOMaC was in charge of the preparation of optical fibres for a prototype detector representing a candidate technology for the upgrade of the NEXT experiment:

- An informal collaboration was established for the construction of this prototype.
- Saint-Gobain WLS optical fibres were polished, cut and aluminized (light yield RMS~7%).
- The fibres were sent to Israel (U. Ben Gurion) where the assembly and tests of the prototype are ongoing.
- The results from the prototype tests are important for the options of development of this new gaseous Xe detector as well as a possible formal collaboration of LOMaC.

LOMaC, with the Dosimetry group, participates in developing a scintillating optical fibre microdosimeter. The LOMaC expertise has been in hand in several stages during design, assembly and characterization:

- The concept and design of the microdosimeter prototype using 1 mm diameter fibres juxtaposed in planes.
- Optical fibres characterization using the fibremeter.
- Fibres polishing in a bundle and aluminization using the Sputtering setup.
- Production of the juxtaposed fibre planes.
- Fibres glueing to dedicated 64-pixel connectors for the MAPMT readout and polishing.
- Characterization of the fibre planes.
- Tests of the microdosimeter prototype using X-rays.

Lines of work and objectives for next year

For 2023, the reequipment program will approach the end, with the setup of a dark room to test plastic scintillators using light sources, and the purchase of some fundamental electronics units and also units to replace broken ones – the continuous large interventions in the building had generated strong perturbations in the electrical network that may be contributing to the loss of electronics units.

The tilemeter improvement will continue. After the testing of several SiPMs and small PMTs, mechanical enclosures still need to be done for practical coupling with scintillators and fibres. Concerning the aluminization facilities, the sputtering equipment is operational and regular maintenance and small improvements will be done.

Tests of the new TileCal High Voltage system will continue, with new test systems that will be used to test the last prototypes of boards and cables. Aging studies of TileCal optics focusing on scintillators and fibres will continue, benefiting from new data from the LHC Run 3, and higher dose exposure to improve statistical uncertainties. We also plan to publish a dedicated paper with the results of the study.

In the framework of the Dlight project and the FCC group, samples of larger PET/PEN scintillators, as well as samples using mixtures of the two materials, will be produced at IPC/UMinho and will be characterised at the LOMaC facilities. The simulation required for comparing the light yield of the small samples produced with the reference tile will be completed. The results of the study of these new materials will be published.

The scintillators developed are expected to be used in prototypes of TileCal-like calorimeters for future detectors at the FCC or other facilities. This will be a contribution to the implementation of the ECFA Detector R&D Roadmap work package TF6 – Calorimetry. Under the same line, we will continue simulating the performance of a TileCal-like design for an FCC-ee detector. The next step is integrating the current standalone calorimeter simulation into a full detector package, allowing to simulate the jet energy resolution and to probe the impact of particle flow reconstruction.

The collaboration with the LIP Dosimetry Group will continue towards developing and testing of a microdosimetry prototype.

Medium-term (3-5 years) prospects

In the medium term, LOMaC contributions will focus on three areas. The first one is the Tile calorimeter of ATLAS and associated detectors. There will be work in the search for radiation-hard scintillators and WLS fibres for the future replacement of the gap/crack scintillators for the HL-LHC runs. At the same time, there will be an effort to better estimate the degradation of the main scintillators and WLS fibres of the TileCal that are essential for the next runs of the LHC and HL-LHC, as they cannot be replaced.

The second area is to contribute for future scintillator based detectors. Performance studies of future calorimeters based on simulations are being planned in collaboration with CERN, and work will start towards a small prototype. In terms of detector R&D for the future, our activity will naturally be informed by the ECFA Detector R&D Roadmap specifications.

The third area corresponds to applications in microdosimetry. After the conclusion of a first prototype the collaboration with the Dosimetry Group will continue aiming at the design and fabrication of a newer and improved version of the microdosimeter.

SWOT Analysis

Strengths

Long-standing expertise in the test, preparation, and aluminization of plastic optical fibres for detectors. Only a few facilities of this kind exist in the world. LOMaC is fundamental for the ATLAS TileCal upgrades.

Weaknesses

Aging equipment needing replacements and upgrades.

Opportunities

The FCC-hh Conceptual Design Report has demonstrated that the TileCal design is still one of the best for a hadronic calorimeter. This opens the opportunity to participate in new detectors in HEP or related fields.

The ECFA Detectors R&D Roadmap implementation, with the new Detector R&D Collaborations, opens new opportunities to boost our R&D on scintillators and calorimetry for the future colliders and attract new funding to support them.

The LIP Summer Internship program and the PT-CERN PhD grants started to attract young people interested to work in the areas of activity of LOMaC.

Threats

Lack of sustained operations of the main fibre preparation facilities is possible.

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Rute Pedro (António Pontes)	FCT	49.964 €	2022-01-01 to 2023-06-30	EXPL/EME-NUC/1311/2021 / DLight: New Plastic Scintillators for Future Light-based Detectors

RESEARCH INFRASTRUCTURES

TAGUSLIP

TagusLIP laboratory

Coordinator:
João Varela

1 ***Technician(s):***
Rui Pereira da Silva

5 ***External collaborator(s):***
Luis Ferramacho, Miguel Silveira, Ricardo Bugalho, Rui Francisco, Stefaan Tavernier

Executive summary

The TagusLIP Laboratory is a LIP research infrastructure installed in 2004 at the Lisbon Science and Technology Park (Taguspark). TagusLIP was conceived as a generic infrastructure for the development of radiation detectors in the areas of PET imaging and experimental particle physics. The main users of the TagusLIP Laboratory are presently the LIP-CMS group and the start-up company PETsys Electronics.

TagusLIP

Overview

The TagusLIP Laboratory is a LIP research infrastructure installed in 2004 at the Lisbon Science and Technology Park (Taguspark). The campus is home to a University (IST), several research centres as well as a large spectrum of startup's and PME's.

TagusLIP was conceived as a generic infrastructure for the development of radiation detectors in the areas of PET imaging and experimental particle physics. TagusLIP includes detector and electronics laboratories, electronics workshop, offices space, and meeting rooms.

The TagusLIP laboratory is equipped with the necessary instrumentation for R&D on radiation detectors and associated electronics and data acquisition, including electronics lab equipment, computing and networking systems. The laboratory offers software tools for developing analog and digital electronic integrated circuits, for firmware development, and for the design of printed circuit boards. The TagusLIP has a computing and data storage infrastructure, suitable to software projects in various areas, such as data acquisition, equipment control, data analysis and image processing. The TagusLIP is licensed for the use of radiation sources needed to develop and test new instruments in nuclear medicine.

The research teams that traditionally have been using TagusLIP have large experience in the development, commissioning and operation of large detectors in Particle Physics experiments and medical instruments. The LIP-CMS group has developed and installed the Data Acquisition System of the Electromagnetic Calorimeter of the CMS experiment. TagusLIP was home to the integration and commissioning of two PET scanners dedicated to mammography developed by the national PET-Mammography Consortium led by LIP in the framework of the Crystal Clear Collaboration at CERN. The LIP group Spinoff Technologies for Cancer Detection (STCD) developed long experience in the design and implementation of detector readout ASICs, in particular the ClearPEM ASIC for APD readout, and the TOFPET1 ASIC for Time-of-Flight applications with SiPMs developed in the framework of the EU project EndoTOFPET-US. In synergy with the STCD group, the LIP-CMS group developed the TOFEE ASIC for the readout of LGAD fast silicon sensors for the CT-PPS proton spectrometer in collaboration with INFN/Torino.

The development of TOFPET1 ASICs for PET Time-of-Flight applications was at the origin of the creation of the start-up company PETsys Electronics in 2013. The shareholders of PETsys Electronics are the venture capital company Portugal Ventures, several institutional shareholders of the mother company PETsys Systems including LIP and other institutional partners of the PET-Mammography Consortium, as well as individual collaborators. A technology transfer contract between LIP and PETsys Electronics included in the process of creation of the company transferred the TOFPET1 IP from LIP to PETsys Electronics. The company PETsys Electronics has been using the TagusLIP infrastructure under the terms of a protocol established with LIP. The TagusLIP operation costs are presently shared between LIP and PETsys Electronics.

Benefiting from the infrastructure available at TagusLIP, PETsys Electronics was able in the past 10 years to develop considerably its activities and to become a main contender in the market of readout electronics for photosensors. PETsys Electronics developed a new ASIC for SiPM readout (TOFPET2) with increased performance, and developed also complete SiPM readout and data acquisition solutions for detector systems with tens of thousand channels. Under contract with LIP/CERN, the company has developed a new front-end ASIC (TOFHIR2) for the new MIP Timing Detector of the CMS experiment.

Assessment of the past year: objectives vs. achievements

In 2022 the main users of the TagusLIP Laboratory were the LIP-CMS research group, in the frame of the Upgrade projects towards HL-LHC, and the start-up company PETsys Electronics. The following activities have been performed by the LIP-CMS group were the following:

1. Validation of the TOFHIR2 ASIC
    1. The development of the new ASIC TOFHIR2 for the new CMS Barrel Timing Detector (BTL) was pursued in collaboration with PETsys Electronics. LIP was responsible for the TOFHIR2 test boards and the chip characterization.
    2. The results with the first prototypes TOFHIR2A, TOFHIR2B and TOFHIR2X showed excellent performance matching the simulation expectations. TOFHIR2 chips coupled to sensor modules (LYSO and SiPM) were tested at TagusLIP. The timing performance was as expected. The validation of radiation tolerance was done at CERN (X-rays) and at the Heavy Ion Facility in Louvain.
    3. A CMS Review of the TOFHIR2 ASIC took place in October 2022. About 15'000 chips have been ordered in November 2022 (Engineering Run).
2. Development of the MTD/BTL front-end readout system
    1. The LIP group has the full responsibility for the design, production, and testing of the Front-end Cards.
    2. After the

successful validation in 2020 of the first prototype of the BTL Front-End Board integrating TOFHIR1 ASICs, the group pursued the development of the second prototype (FE_v2) following a substantial re-design of the BTL readout system. Prototypes of the new Front-End board have been fabricated and tested successfully.

A pre-series of the final card (120 cards) with TOFHIR2 chips were fabricated and tested successfully

Development of the production test systems of the TOFHIR2 chips in BGA package (15'000 chips) and of the Front-End Boards (5500 boards). This activity will be concluded in 2023.

Development of prototypes of timing detectors for the future PPS detector at HL-LHC in synergy with the MTD project.

1. In the frame of a dedicated funding, the LIP-CMS group has initiated the development of prototypes for the future timing detectors of PPS. The sensors and frontend electronics are based on LGAD and the ETROC chip used in the MTD/ETL.

The results obtained were presented at several international conferences, including IEEE/NSS/MIC 2021 (online conference).

Lines of work and objectives for next year

The TagusLIP space continues to be shared by LIP and the company PETsys Electronics. Reflecting the growth of the company, a new space with twice the area will become available in September 2023. New infrastructures installed by PETsys will also benefit the CMS Upgrade project, namely:

1. Automatic ASIC test system
2. Climatic chamber for reliability testing of electronics systems

The main activity in the CMS Upgrade project will be the organization of the final production of TOFHIR2 BGAs and Front-End Boards for the experiment. The production testing has been contracted to PETsys Electronics after an international tender organized by LIP.

Medium-term (3-5 years) prospects

In the next two years the TagusLIP will be used for the production and testing of the readout system of the CMS timing detector. About 15000 TOFHIR2 ASICs and 5000 BTL front-end boards will be tested. The R&D towards the Phase-II Upgrade of the PPS timing detector will also be carried at TagusLIP. This will imply an upgrade of the infrastructure with equipment necessary to the development of silicon sensors for timing.

SWOT Analysis

Strengths

Strong technical team and long expertise in radiation detectors. Excellent integration at international level. Complementarity and synergies with PETsys Electronics.

Weaknesses

Presently the infrastructure is dependent on the sales of PETsys Electronics and the CMS Upgrade program.

Opportunities

Possible growth of PETsys Electronics, opening the possibility of research contracts between LIP and the company.

Threats

Lack of dedicated funding for R&D activities in medical applications.

COMPETENCE CENTRES


Monitoring and Control
Competence Center
Simulation and Big Data
Competence Center

COMPETENCE CENTERS

CCMC

Competence Center in Monitoring and Control

Coordinator:
Francisco Neves

2 ***Researcher(s):***
Filipe Veloso , Helmut Wolters

1 ***Technician(s):***
João Carlos Silva

3 ***Master Student(s):***
José Rodrigues, João Parente, Rita Barradas

7 ***Undergraduated Student(s) and Trainee(s):***
Alexandre Jorge Leitão Nunes, Jamie Bockett, João Tiago Ramos Costa, Luís Filipe Ventura de Melo, Luís Januário Paiva, Lídia Sofia Neves Faria, Sandra Silva Taborda Mamede

Executive summary

The main purpose of the Competence Center in Monitoring and Control (CCMC) is to gather the expertise in the design, implementation and operation of monitoring and control systems accumulated by LIP groups in the context of their scientific activities. Besides facilitating the sharing of this body of knowledge (including sensors, electronics and software) among LIP members, the CCMC intends also to establish partnerships or contracts with third parties (e.g. other research laboratories, industry) as a means to transfer scientific know-how and solutions into the community. Regarding the latest, another key objective of the CCMC concerns the training of human resources and the development of outreach instruments.

CCMC

Overview

The Competence Center in Monitoring and Control (CCMC) is a small transversal LIP infrastructure consisting basically of human resources scattered among different fields of activities: from low energy and rare event searches to high energy particle physics and computing. This diversity is key to fulfill its main objective of gathering different expertise from different backgrounds and areas of scientific research.

The group activities are focused on the design, development and coordination of user-specific solutions for monitoring and control including all required software tools, usually delegating the manufacturing of electronics and other hardware to the LIP electronics and mechanical workshops. Besides the hardware and respective firmware, the group also develops analysis tools required to extract information from the data being collected. The workload is usually divided among the CCMC members according to their availability and dedication to their scientific projects.

Assessment of the past year: objectives vs. achievements

1. In partnership with the ECOTOP project of the MARE research centre, secured funding from the Technology Transfer Office of the University of Coimbra ("INOVC+ Ignition Project and Proof of Concept" call) for the project "MonNest – Nest Monitoring". The project aims at developing and building a kit for environmental, physiological and behavior monitoring of nesting birds in cavities, to better understand and quantify the impact of climate change and thermal stress as well anthropogenic pressure affecting bird population.
2. In collaboration with MARE-ECOTOP, continued to develop the analysis of the data (egg temperature and heart rate) collected during previous seagull breeding seasons using the dummy eggs (hardware+firmware) developed by the CCMC. The new analysis being developed uses Machine Learning (ML) techniques and aims at improving the heart rate measurement and to associate it with bird behavior features of interest (e.g stress triggers).
3. The collaboration with the LIP-LZ group towards the integration of database tools in the analysis framework developed by the LIP team for the real time Data Quality Monitor (DQM) was completed.
4. Participation in the summer internship program at the University of Coimbra for undergraduate students with the project:
    1. Development of analysis tools for a cloud chamber (3 students).
    2. Audio analysis: measuring heart rate and classifying heart sounds (3 students).
5. Supervision of three master studentsin the following areas:
    1. Development of a non invasive temperature monitoring device with image/target recognition. In collaboration with industry (Bosch Termotecnologia, Aveiro). Completed;
    2. Development of Machine Learning Tools for the extraction of behavioral and physiological parameters of nesting birds in their natural environment (ongoing).
    3. Development of embedded systems for heating, ventilating and air conditioning (HAVAC) and machine learning in microcontrollers (completed).
6. Started to build at the LIP mechanical and electronics workshop the upgraded version of the cloud chamber prototype previously developed by the CCMC (3 units). The upgrades aim at optimizing multiple aspects in the design and operation of a low cost chamber to be used in outreach activities.

Lines of work and objectives for next year

1. Execution of the project "MonNest – Nest Monitoring" funded by the Technology Transfer Office of the University of Coimbra. Upon completion, a prototype of a kit for environmental, physiological and behavior monitoring of nesting birds in cavities should be ready.
2. Prepare two papers on the work being carried out with MARE-ECOTOP and the dummy eggs produced by the CCMC: one focused on the monitoring hardware and analysis tools; the other, with the analysis of the collected field data.
3. Expected to produce one paper from the work carried out with Bosh Termotecnologia.
4. Continue to invest in dissemination activities, namely at the undergraduate level, as a tool to attract high quality human resources.
5. In what concerns the training of human resources, continue to invest in the co-supervision of master's in the industry, as it also represents a privileged vehicle to disseminate our capabilities aiming at future collaborative projects.
    - Currently an MSc supervision is being negotiated with an industry partners (The Loop co., Coimbra, Portugal) for modeling and detection of leaks in public water distribution networks.
6. Efforts are underway to pursuit possible new contracts/projects with industry partners (Please do not make this information public):

1. Build a MCA board for HP Ge Detectors (Vitalchem);
2. Build a general purpose magnetometer (Active Space Technology);

   The CCMC will have a collaborator (0.6 FTE, 6 months) dedicated to perform market prospection and production of a portfolio.

   Assemble the cloud chambers and produce its firmware, including the capability of real time identification and display of particle tracks. The instrument, made of low-cost materials, will be available for sale to the public, namely schools.

Medium-term (3-5 years) prospects

1. In order to achieve the CCMC objectives, it is required during the upcoming years to develop more effective tools to reach a wider set of potential partners and clients. The previous years already show a slow but effective growth in activities with third parties which, although perfectly aligned with the CCMC objectives, also unveiled the need of more collaborators to be able to respond to new responsibilities/solicitations.
2. Continue to invest in the training of human resources/student supervision in collaboration with the industry, as it represents a privileged vehicle for looking for new project opportunities outside of the universities and matches LIP's technology and knowledge transfer goals.

SWOT Analysis

Strengths

- A large body of knowledge accumulated from the participation of LIP members in several experiments, often with direct responsibilities in the development, constructions and maintenance of monitoring and control subsystems.

Weaknesses

- Do not have (explicit) allocated FTEs for the development and execution of projects.
- The current inability to certificate products and services.

Opportunities

- The ability to deploy very high quality products and services developed within scientific projects and meeting very high quality and reliability standards.

Threats

- The ability to meet deadlines and ensure the humanpower required for the assistance to services/products contracted with third party entities.

CCMC

Publications

1 LIP Students Note(s)

- *"Aplicação de métodos de Machine Learning e Deep Learning na análise de batimentos Cardíacos"*, Sandra Silva Taborda Mamede, LIP-STUDENTS-22-07

Presentations

1 Oral presentation(s) in national or international meeting(s)

- Filipe Veloso: *"Competence Center on Monitoring and Control"*, 2022-07-09, Jornadas LIP 2022, Coimbra

Theses

3 Master

- José Rodrigues: *"Embedded systems for heating and machine learning in microcontrollers"*, 2021-09-01 / 2022-09-28, (finished), UC, Supervisor(s): Filipe Veloso
- Rita Barradas: *"Non invasive temperature monitoring device"*, 2021-09-01 / 2022-09-30, (finished), UC, Supervisor(s): Francisco Neves, Filipe Veloso
- João Parente: *"Development of Machine Learning Tools for the extraction of behavioral and physiological parameters of birds in their natural environment"*, 2020-09-01 , (ongoing), UC, Supervisor(s): Francisco Neves

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Francisco Neves		4.750 €	2022-10-03 to 2023-06-30	UC/INOVC + / MonNest / MonNest – Nest Monitoring

COMPETENCE CENTERS

SIMBIGDAT

Competence Centre on Simulation and Big Data

Coordinator(s):
Bernardo Tomé,Nuno Castro

10 ***Researcher(s):***
Alexandre Lindote, Cristina Mendonça, Filipe Veloso, Guilherme Milhano, Vladimir Solovov, Inês Ochoa, José Reis, Liliana Apolinário, Miguel Romão, Paulo Brás

3 ***Technician(s):***
Henrique Carvalho, Paulo Almeida, Tiago Gonçalves

6 PhD Student(s):
Íris Damião, João Pedro Gonçalves, Maura Teixeira, Fernando Souza, Ricardo Barrué

3 Master Student(s):
António Oliveira, Céu Neiva, Tiago Duarte

2 Research Student(s):
Miguel Peixoto, Gabriela Oliveira

8 ***Undergraduated Student(s) and Trainee(s):***
Gabriela Oliveira, Jhonathan Martinez, Joan Kladnik, Junda Tong, Miguel Peixoto, Ruby Mckenna, Tiago Antão

17 ***External collaborator(s):***
Albano Alves, António Esteves, Bruno Galhardo, Diogo Gonçalves, Filipa Peres, Francisco del Aguila Giménez, Johannes Erdmann, José Rufinoo, José Santiago Perez, Kevin Kroeninger, Korinna Zapp, Pedro Martins Ferreira, Pier Parpot, Rui Santos, Tobias Golling, Vitor Oliveira, Ana Peixoto, Tiago Vale, Guilherme Guedes

Executive summary

The purpose of the Competence Center (CC) on Simulation and Big Data is fostering an effective collaboration between the different LIP groups working on these areas and to boost the capability to exploit the existing expertise both internally and externally, towards the academia and industry. The different LIP groups have a vast range of competences in data science and simulation tools, including physics models, Monte Carlo generators, detector simulation, big-data analytics and data mining. The ability to fully benefit from such competences requires achieving critical mass, a coordinated training program, the exploitation of synergies between groups and a clear identification of the key areas in which we can contribute in a competitive way.

The first funded project of the Competence Center was successfully completed in 2021 and, in 2022, two new exploratory projects started: one devoted to machine learning in quantum computing and another in collaboration with the Physics Center of the University of Minho, devoted to the use of machine learning for new materials.

The core activity of the Big Data part of the CC continues to be the use of machine learning techniques for the different data analysis done by different groups at LIP, with ATLAS, LZ and SWGO being currently the most active ones in this context. The team is consolidating the experience on anomaly detection techniques in experimental context, where uncertainties play an important role. A close collaboration with the LIP Computing group and the National Infrastructure for Distributed Computing (INCD) has been pivotal to the activities of the Competence Center. The use of containers and the corresponding training of the different teams has gained relevance in the context of data preservation and reproducibility. Along these lines the collaboration with the SPAC group has been enhanced.

For the simulation part, advanced teaching/training and support to the simulation production needs of the LIP groups, researchers and graduate studens remain as central tasks. The solid expertise in GEANT4 is complemented by the specific contributions to the GEANT4 collaboration, which should be continued and expanded. The training of students and researchers in simulation and machine learning continues to be one of the main goals of the Competence Center, as well as sharing this expertise within LIP and beyond.

SimBigDat

Overview

The Simulation branch of the competence center developed the following activities:

- Teaching of advanced detector simulation techniques as part of the curricula of specific undergraduate courses and doctoral programs. Continued support to PhD students developing simulation work was assured.
- Participation in the GEANT4 collaboration was continued. The support and maintenance to one Advanced Example, for which LIP is responsible, was maintained, namely in preparation for the release of version 11.1 of GEANT4, by the end of 2022.
- Support to the specific needs of LIP research groups was maintained.
- Further developments to VRLab were undertaken. The Virtual Radiation Laboratory (VRLab) is a set of GEANT4 Applications, initially developed for the Simulation of a Geiger-Mueller counter, of a gamma-ray spectroscopy experiment and of a Positron Emission Tomography setup with implementation of the corresponding image reconstruction algorithm. These GEANT4 applications were interfaced via Python with a graphical user interface, allowing the users to choose the conditions of the experiments. The Interface also allows to display graphic distributions with the results of each virtual experiment: number of Geiger-Mueller counter counts, gamma ray spectra, reconstructed emission position of the two gammas in the case of the PET experiment. The VRLab was started in 2018 with IST MsC Engineering Physics students taking the course “Nuclear and Particle Physics Technologies". Since the beginning of the development of the application several improvements have been, including the integration of anthropomorphic phantoms in the PET virtual experiment and the addition of a silicon detector option to simulate the energy deposited in this type of detectors from several different radioactive sources. In 2021/2022 a charged particle therapy simple set up was added by internship students. Also in 2022, a preliminary module for the simulation of the Martian, Lunar and Earth atmospheres - PlanetRAD - was developed, to serve as a laboratory setup for students for the Space Physics course of the IST minor on Space Science and Technology.

The Big-Data branch of the competence center developed the following activities:

- Study and development of machine learning techniques for the detection of rare events at colliders and scanning of the parameter space in new physics models.
- Study of tools for generator-level information to estimate a detector-level optimal observable sensitive to CP violating components in the HWW interaction in leptonic WH production.
- Development of machine learning techniques to discriminate muons and gammas in cosmic-ray-induced showers, a very important aspect for the design of SWGO.
- Development of quantum machine learning models, tackling the challenges of the size of datasets for the current quantum computers and comparison with classical machine learning techniques.
- Training of students at different levels (undergrad, MSc and PhD).
- Organization of the 3rd School and Symposium “Data Science in (Astro)Particle Physics and Cosmology: the Bridge to Industry”, in Coimbra (June 2022).
- Active participation of members from the ATLAS, Pheno and SPAC groups in the Analysis Preservation workshop, an event supported by CERN and the IRIS-HEP institute, providing training in topics like Docker, Apptainer and Continuous Integration. These technologies help increase the robustness and reproducibility of scientific computing, particularly useful in analyzing large datasets in cluster environments.
- Ongoing collaborations between members of different LIP groups (ATLAS, CMS, Auger, LATTES, Dark Matter, Phenomenology, SHiP, SPAC) in the context of machine learning, including providing dedicated computing resources.
  Collaboration with groups beyond HEP, namely on the use of machine learning in the context of condensed matter physics. This collaboration led to a funded national project, which supported the acquisition of a dedicated server for machine learning, managed by LIP.
- Collaboration with the LIP Computing Group and INCD for efficient exploitation of computing resources, namely for the training of machine learning models.
- Successful application to computer time within the national call for scientific computing (RNCA).

Assessment of the past year: objectives vs. achievements

On the Simulation side, several developments were undertaken in the context of the specific activities of the LIP groups:

- Training on advanced detector simulation, at undergraduate and graduate levels.
- Participation in the GEANT4 collaboration was continued, with development and support responsibilities by LIP members.
- Support to the specific needs of LIP research groups.
- Developments to the VRLab were continued, in particular with the inclusion of a new module, PlanetRAD. PlanetRAD is based on a simplified version of the dMEREM package (detailed Mars Energetic Radiation Environment Model, developed by the SpaceRAD group). Using this tool, visualization of energetic particle showers in different scenarios can be explored: Earth, Mars and Moon surface together with Interplanetary Space using different radiation sources (cosmic ray fluxes during solar minimum/maximum period), different SEP (Solar Energetic Particles) spectra or monoenergetic particles. An analysis tool to obtain the primary and secondary particle spectra together with effective and ambient dose was also developed.

On the Big Data side, the QML project was started, and promising results on the use of quantum computers for analysis of collider data were obtained.

Most of the LIP groups are now commonly using advanced machine learning techniques and the Competence Center provides a forum for discussion, collaboration and leveraging of new ideas. The use of machine learning for model building and identification of new experimental observables was one of the main lines of work of the CC in 2022, as well as the use of deep learning for the discrimination of muons and gammas in cosmic-ray-induced showers.

A common area of interest between groups has been data preservation, with technologies such as containers being now commonly used at LIP.

A close collaboration with the Computing group, as well as INCD, allowed to fully exploit the available computation resources and some of the team members succeeded in their application to CPU and GPU hours in the national call for access to scientific computing clusters. The CC had an important role in pivoting synergies between INCD and SPAC, namely on the parallel running of scripts to train web bots, in diverse geographic locations, which was relevant for the recently awarded ERC Proof of Concept grant.

The collaboration with the Physics Center of the University of Minho on the use of machine learning for the determination of the structure of new materials was also continued.

Lines of work and objectives for next year

The Simulation branch of the competence center will continue to contribute to the teaching of advanced detector simulation methods at graduation and doctoral programs. The participation in the GEANT4 collaboration and the maintenance of an Advanced Example, will be continued. In particular, code review including the implementation of the extended examples coding guidelines and migration to C++17 is foreseen. Continued support to the specific needs and/or requirements of the LIP groups will be assured. Further developments to the VRLab tool are foreseen, in particular with the improvement of its medical physics related component.

In what concerns the Big Data part of the Competence Center, we will continue the ongoing work on anomaly detection and its application to HEP and beyond. This is a popular area in the machine learning community now, but HEP has some specific needs, namely the statistical interpretation of the results and the resilience of the different techniques to systematic uncertainties. Some of the techniques developed within the Competence Center are being used in the search for new physics events at ATLAS and the search for rare events in LZ. This dissemination of the work in the experimental collaborations will be continued and expanded. The use of machine learning for model building has demonstrated promising potential and will continue. The synergies with the SPAC and the Computing groups on the use of distributed computing resources and analysis of extensive datasets will be strengthened.

Furthermore, the tightening of collaborations between LIP members and external collaborations will be pursued. Deep learning techniques are now commonly used in the community and even if applications can be very different, common work can leverage the impact of LIP members in HEP and in the society at large. The use of quantum computing in this context will also be studied as an exploratory line of the Competence Center.

Medium-term (3-5 years) prospects

The medium term strategy of the Simulation and Big Data Competence Center aligns, naturally, with LIP's strategy.

Therefore, we should be able to contribute in a transversal way to all the strategic areas with needs in terms of simulation and complex data handling.

The main challenge for the Competence Center is its consolidation in an extremely competitive area, following the plan defined at its creation: to expand LIP's competences in this area by exploiting synergies between the different groups, implement a training program and establish partnerships with the academic and industrial communities interested in this field. The foreseen opportunities in terms of digital society and digital transformation will be explored.

SWOT Analysis

Strengths

- Long standing expertise in simulation and big data at LIP.
- Expertise in modern data mining techniques used in HEP and beyond.
- Integration in international collaborations (HEP experiments, GEANT4 collaboration).
- Diverse team, consolidated by competitive fundings secured by the Competence Center.

Weaknesses

- Despite having more researchers and students working in this field, we are still below the critical mass in some areas and do not reach equally all the LIP groups using simulation and machine learning.
- Difficulties to attract and retain talent in areas with large demand for trained people outside academia, such as computing and data science.

Opportunities

- Huge interest and demand for expertise in simulation, big data and data mining.
- The Horizon Europe programme has a strong focus on Digital Transformation.
- The Data Science Symposium allows us to get in close contact with a significant number of companies (services and industry).
- Big interest of students in artificial intelligence and machine learning.

Threats

- These areas are extremely competitive, involving a community much larger than the HEP community.
- Dispersion of efforts in areas where we cannot be competitive.
- External services in simulation and big data are highly competitive outside some niche areas.

SimBigDat

Publications

2 Articles in international journals (with direct contribution from team)

- *"Search for pair-production of vector-like quarks in pp collision events at s√=13 TeV with at least one leptonically decaying Z boson and a third-generation quark with the ATLAS detector"*, N. Castro, T. Vale et al. (ATLAS Collaboration), PLB, arXiv:2210.15413
- *"Fitting a Collider in a Quantum Computer: Tackling the Challenges of Quantum Machine Learning for Big Datasets"*, Miguel Caçador Peixoto, Nuno Filipe Castro, Miguel Crispim Romão, Maria Gabriela Jordão Oliveira, Inês Ochoa, arXiv:2211.03233

2 LIP Students Notes

- *"Anomaly Detection in all hadronic boosted final states"*, Junda Tong, LIP-STUDENTS-22-02
- *"Search for New Phenomena in the Top quark sector using Anomaly Detection"*, Inês Pinto, Joan Kladnik, LIP-STUDENTS-22-14

Presentations

2 Oral presentations in international conferences

- Nuno Castro: *"Rare production and decay processes in the top quark sector"*, 2022-05-19, 10th conference on Large Hadron Collider Physics - LHCP 2022, online
- Nuno Castro: *"EOSC activities in the High Energy Physics community"*, 2022-10-10, IBERGRID 2022, Faro, Portugal (presentation online)

1 Presentation(s) in national conference(s)

- Nuno Castro: *"CERN and particle physics: challenges and opportunities"*, 2022-05-16, Encontro Ciência 2022, Lisboa

Organized Events

1 International Conferences or Workshops

- *"Data Science in (Astro)Particle Physics and Cosmology: the Bridge to Industry"*, [Conf-WS-Int] 2022-06-27 / 2022-06-30, Coimbra

Theses

1 PhD

- Fernando Souza: *"AutoBSM: Validating Beyond the Standard Model Physics with Machine Learning"*, 2022-05-01 , (ongoing), UMinho, Supervisor(s): Miguel Romão, Nuno Castro

1 Master

- Céu Neiva: *"Advanced machine learning techniques in rare events research at the Large Hadron Collider"*, 2020-09-01 / 2023-02-01, (finished), UMinho, Supervisor(s): Nuno Castro, Miguel Romão

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Nuno Castro		18.750 €	2022-01-01 to 2024-12-31	PTDC/FIS-MAC/2045/2021 / Excitações em materiais quânticos 2D/INL
Miguel Romão (Inês Ochoa)		30.000 €	2022-02-01 to 2024-01-31	CERN/FIS-COM/0004/2021 / QML-HEP: Exploring quantum machine learning as a tool for present and future high-energy colliders

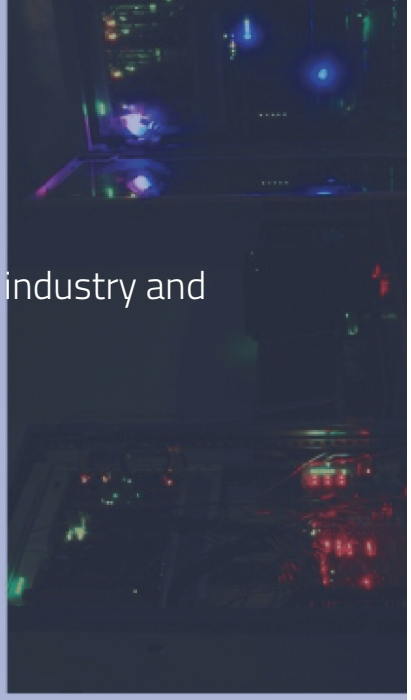
Science and Society

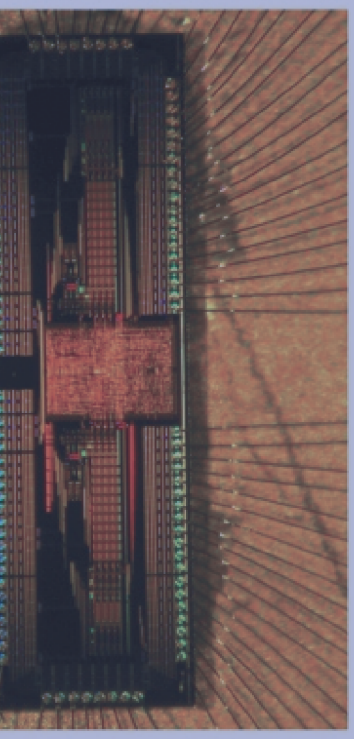

Knowledge transfer, industry and spin-offs
Radiation, health and environment
Muon Tomography

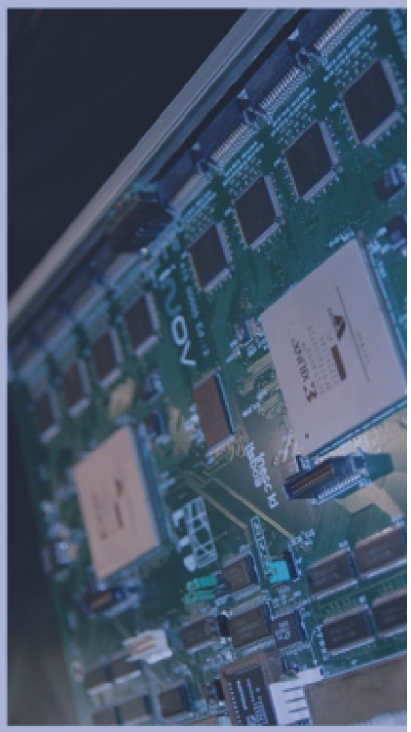
SCIENCE AND SOCIETY

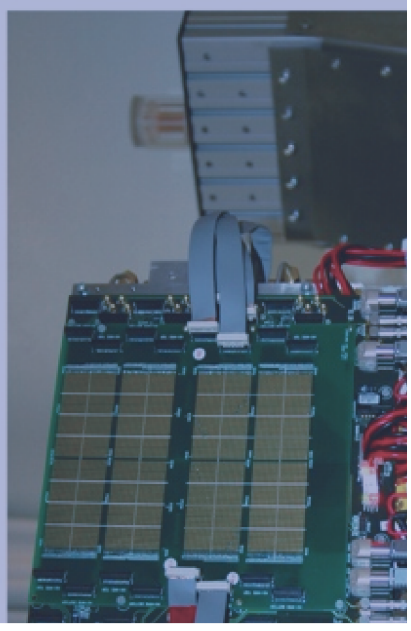
KT

Knowledge Transfer, industry and spin-offs









KT

Overview

Strategic areas for LIP's KT are healthcare, space application, data science and digital technologies. The list of companies the LIP groups have collaborated with in the last 5 years includes Adductio, Bosch, Cabelte, Dialog Semiconductors, EFACEC, EVOELEO, Grupo ASSEC, HIDRONAV (Spain), ICNAS-Produção, Ideas (Norway), Kinetic (UK), Nielsen, NuRise, PETsys, Siemens, Silicon Gate, Systion, Tellspec and Wavecom. Some of the main Portuguese research units and other public institutions we collaborated were CEFITEC/ NOVA, Centre of Physics and Centre of Chemistry and UMinho, CFTC/FCUL, CFTP/IST, Champalimaud Foundation, CHUC, CTN/IST, FCCN/FCT, GHIPOFG, Hospital de Santa Maria, IBEB/FCUL, ICNAS, ICT/U. Évora, INCD, INESC-ID, INESC-TEC, LNEC, MACC, MARE.

As CERN's reference institution in Portugal and a recognized partner of ESA, LIP has a special role promoting the internationalization of Portuguese companies and helping to create opportunities to increase the industrial return to Portugal. More than three decades of high impact contribution to international collaborations at CERN and in other international scientific infrastructures have proven a successful way to achieve these goals — by proposing partnerships, providing support or facilitating a first contact.

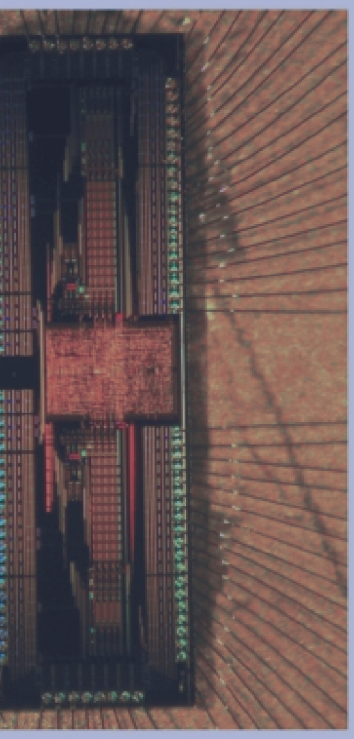
LIP keeps a close connection with the representative of Portugal in the CERN KT forum (José Antão, ANI), with ESA's Industrial Policy Committee representative at PT Space, and represents Portugal in the CERN KT forum for medical applications, in HEPTech, a European Network devoted to KT from large scale HEP science projects and research facilities, and in several European computing infrastructures and initiatives. LIP is a member of the PERIN network.

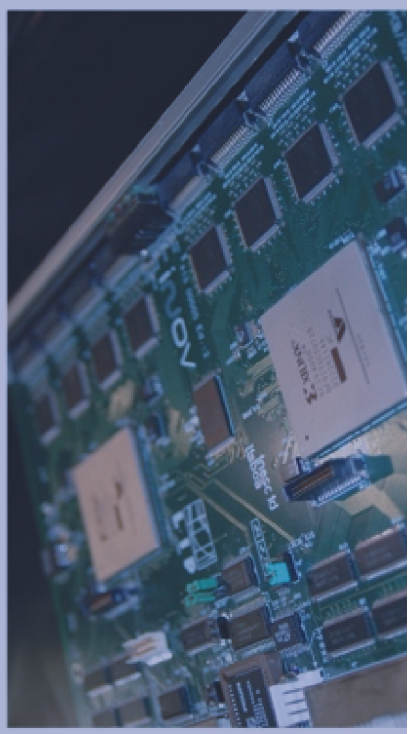
LIP directly involves graduate students in collaborative, multidisciplinary, innovation projects with companies and other external entities, through internships, technology-oriented advanced training and the inclusion of an applied research component in their projects. This enhances their level of employability in the private sector and contributes to increase the qualification of the human resources in Portuguese companies.

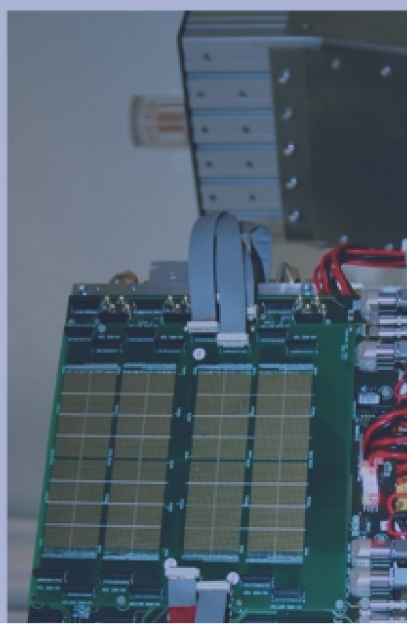
SCIENCE AND SOCIETY

GRANTS OFFICE

Team:
Natália Antunes, Rita Saraiva, Margarida Rodrigues







Executive Summary

The mission of the Grants Office (GO) at LIP is to empower researchers to fund their ideas by helping them navigate the diversity and complexity of international funding schemes and submit highly competitive research proposals. Besides directly supporting researchers drafting and submitting their applications for funding, the GO liaises with relevant stakeholders including LIP's accounting offices and board of directors, colleagues and researchers from other R&D institutions, and National Contact Points (NCPs).

Grants Office

Overview

The GO was established in early 2021, shortly after Rita Saraiva joined LIP. The team entails 3 people: Rita Saraiva, who acts as the core team member, providing specialised reviewing services to individual grant submissions, and Margarida Rodrigues and Natália Antunes, who give administrative and technical support as needed, in their respective Coimbra and Lisbon LIP nodes, all of them simultaneously carrying out other roles at LIP. The team members share the tasks related to the communication and dissemination of funding opportunities, and work closely with Luísa Arruda and Catarina Espírito Santo to best match funding sources to potential applicants.

Assessment of the past year: objectives vs. achievements

Since the inception of the GO, one of the main priorities has been the adequate and professional training of its team members. This expert knowledge is critical for its success, not only because of the complex, competitive and changing nature of the international funding landscape, but also due to the relative inexperience of the team. The beginning of the GO also coincided with a new European Union Framework Programme, Horizon Europe (HEU), meaning there were plenty of training opportunities available. In 2022, we reduced the focus on training, as HEU picked up speed and the number of funding applications submitted by LIP researchers increased. We highlight a few examples of proposals supported by the GO: 1) Assisted in the submission of an European Research Council (ERC) Starting Grant, which was unfortunately not funded; 2) Helped the applicant for an ERC Consolidator Grant prepare his interview by organising several mock interviews with LIP colleagues, ERC evaluators, past ERC grantees, and the NCP for ERCs, Rui Munhá. This proposal received the highest score, fully meeting ERC's quality criteria, but couldn't be funded due to insufficient funds; 3) Contributed to the submission of an ERC Proof of Concept Grant that was successfully funded, making it, to the best of our knowledge, the first grant awarded in the scope of an EU Framework Programme where LIP acts as the coordinating institution during the submission process. The GO also supported other types of submissions, including applications to the Research Infrastructures Programme, the European Innovation Council, and the first LIP submission to the La Caixa Health Research Programme. Another early focus of the GO members, especially Rita Saraiva, was building working relationships with colleagues in similar roles in other research institutions. LIP's participation in the informal Pre-award network at Instituto Superior Técnico (IST), spearheaded by Marta Candeias, has been particularly fruitful. The advantages are clear: the GO gains access to a knowledgeable and experienced community, taking part in joint initiatives and sharing available resources, while LIP's researchers can also participate in courses organised at IST, partially compensating for the lack of critical mass at LIP. In this context, during 2022 the GO presented LIP's scientific interests and competences in meetings with the NCPs for Pillar 2, and LIP researchers took part in the Pillar 2 Training Program and the ERC Acceleration Programme, both organised at IST. Similar arrangements are in place with the University of Coimbra for the ERC calls. Other activities pursued during 2022 include the maintenance of an updated list of selected open calls in LIP's intranet website, regular presentations at LIP's scientific council meetings and at Jornadas do LIP, as well as contributions to the drafting and implementation of LIP's Gender Equality Plan.

Lines of work and objectives for next year

The GO was established during the COVID-19 pandemic. As a result of these difficult circumstances, the launch and visibility of the GO was occasionally hindered. The scattered physical locations of the LIP researchers, across Portugal and other countries, also make it harder to build the trust relationships and rapport that facilitate communication and collaboration with the researchers. As such, a more active approach is needed. During 2022, we took the first steps in mapping the scientific interests of the research groups at LIP, with exploratory meetings to discuss the international funding mechanisms that are better suited to their profiles and research subjects. In our experience, these exchanges make the researchers more likely to reach out when they need assistance, or for letting us know when they are planning on submitting an application. In 2023, we want to continue these internal networking meetings: not only do they help us understand the particular interests and contexts of the research groups and design funding strategies, but they also establish a crucial communication channel. These meetings will be held in less busy periods that do not coincide with the main yearly submission deadlines. In addition, the team will carry out its regular activities, including in-depth support to individual proposals according to the goals of each call, and communication and dissemination of funding opportunities, which will be progressively informed by the knowledge gathered in the meetings described above, allowing us to better target potential applicants among LIP researchers.

With help from the community, we will rethink our communication strategy and create work methods to streamline those tasks. We will also look at implementing standard procedures to improve the flow of information within LIP. One of the team members, Rita Saraiva, will be one of the instructors in the next edition of the Pillar 2 Training Program organised at IST and open to LIP researchers. We will also gauge interest in holding special topical sessions at LIP about specific funding mechanisms that might be of particular interest to the community (for instance, ERC grants or FCT R&D project calls).

Medium-term (3-5 years) prospects

In the medium term, the GO expects to increase LIP's ability to attract international funding, particularly from EU public sources, by capacitating LIP's researchers and promoting the submission of competitive proposals. Given that the success rate of LIP's researchers is comparable (or even better) to similar Portuguese institutions covering the same broad scientific areas, the main focus should be on increasing the number of submitted proposals. While we do see an improvement in the number of applications, even if below the most optimistic expectations, this has not yet translated into a relevant boost in international funding. We already perceive an increased interest in international funding opportunities, and we expect that, as the successful results of those applications start coming in, the LIP community will feel encouraged to submit more proposals. These results will also strengthen internal expertise which is currently scarce among researchers. In order to profit from this growing critical mass, it is crucial to keep a healthy and collaborative environment among the research groups and foster knowledge exchange.

SWOT Analysis

Strengths

Nimble and flexible team, that is able to provide in-depth support, tailored to each call. Weaknesses: Team with relatively limited experience, and no academic background in physics. LIP researchers physically scattered across LIP nodes and countries, making relationship building cumbersome.

Opportunities

Leverage the existing close links to researchers at other institutions, in Portugal and abroad, to build competitive consortiums for international funding calls.

Threats

Limited capacity during very busy periods, and often with inadequate advance warning. Diverse skill sets within the team, with little redundancy in case of absences.

SCIENCE AND SOCIETY

RHE

Radiation, Health and Environment

Coordinator:
Luis Peralta (20)

4 Researcher(s):
Conceição Abreu (30), Joaquim Pedro Kessongo (20), Sandra Soares (80), Yoenls Bahu (20)

2 Master Student(s):
Lígia Lopes (24), Nuno Taborda (33)

2 External collaborator(s):
Ana Maia Fernandes, Florbela Rêgo

Total FTE:
2.3 (PhD 1.7)

Executive summary

According to European Directive 2013/59/Euratom, building materials must be analyzed for the possibility of exhaling radon gas. The standard technique for analyzing radon exhalation from building materials consists on enclosing a sample of the material to be analyzed in an airtight container and measuring the amount of radon that accumulates.

The use of high quality detectors and high cost detectors such as the RAD 7 or AlphaGuard is prohibitive when you want to simultaneously make measurements on a large number of samples using several test chambers. One strategy adopted by some laboratories is to use very low cost CR-39 integration detectors. One of the problems with this technique is the fact that possible gas leakage from the chamber is not detected, leading to an underestimation of the exhalation. Our group is developing a system for measuring radon gas daughters inside the container based on low-cost silicon detectors, that can follow the gas buildup inside the chamber in real-time.

Another line of work consists on the analysis of the effect of aerosols containing radon on the antioxidant activity of aromatic plants (M. spicata and P. crispum), and their environmental bioremediation capacity. Each specie under study was divided into two groups: one where exposure to aerosols containing radon occurred and another without such exposure (control). To quantify the antioxidant activity of plants, the DPPH radical scavenging method was used.

The group's members are also actively involved in training activities in the areas of environmental radiation at graduate and post-graduate level.

RHE

Overview

Our group is currently developing a system for measuring radon daughters inside a container which is based on low-cost silicon detectors such as the SLCD-61N2 from ADVANCED PHOTONIX, which will allow monitoring of the gas buildup inside the container. The system is based on a detector concept already demonstrated and published by the group.

The new system, in addition to improving the electronics of the previous one, will allow to distinguish between radon-222 and radon-220 descendants, increasing the reliability of the exhalation measurement system.

In what concerns the analysis of the effect of aerosols containing radon, it was found that plants of the species M. spicata reveal bioremediating properties, absorbing radon and therefore reducing its amount in the environment. About the bioremediation capabilities of plants of the P. crispum species, nothing could be concluded based on the method used.

Assessment of the past year: objectives vs. achievements

During 2022, a new electronics chain was designed (amplification and digitization of the signal given by the detector). The system is currently under testing with samples of material containing uranium oxides. We also purchased a low-cost commercial chamber (less than 100 euros) and carried out radon leakage tests using lid gaskets made of various materials, in order to choose the one that offers the best sealing characteristics.

Work continued on measuring the exhalation of construction materials, although this year activity has decreased due to the lack of students working on the subject.

During 2022 it was possible to perform several experiments with two aromatic plants and we plan to publish the results in 2023.

Lines of work and objectives for next year

Next year we will continue the development of the prototype for controlling the exhalation of materials in a closed chamber.

Also, the work on the effect of radon-containing aerosols on plants will continue with further experimental measurements.

Regarding advanced training, the group secured funding for an international student training project called Blended and Remote teaching Activities supported by Virtual reality for Radiation sciences (BRAVER). The first school was in Prague, the second will be in Bologna and the third in Hasselt and Brussels. The idea is to develop scenarios in virtual reality to illustrate radiation protection issues and instruct about proper radiation protection measures.

Medium-term (3-5 years) prospects

The group hopes to continue the work of surveying radon in the region of Huila, Angola, with the help of members who have returned after completing their PhD.

The group also established a collaboration with the Eötvös Lóránd University Institute of Physics, Hungary, to study the possibility of using the radon detection system that is being developed to monitor wells in a uranium mine. With this collaboration we hope to be able to transfer technology to the area of environmental requalification.

We also have the prospect of increasing collaboration with the construction industry, in terms of certification of construction materials.

We also continue to strengthen our collaboration with the Portuguese Environment Agency.

SWOT Analysis

Strengths

Well equipped laboratory, long term experience in the field.

Weaknesses

Small team.

Opportunities

Collaboration with other national and international institutions and laboratories. Collaboration in the national network for natural radiation assessment.

Threats

Lack of solid financing

RHE

Theses

2 Master

- Lígia Lopes: *"Lecionar através de métodos não convencionais: uma investigação sobre a abordagem lúdica no ensino"*, 2022-07-07 , (ongoing), UBI, Sandra Soares,
- Nuno Taborda: *"Construção de um protótipo para o estudo da exalação de radão por materiais de construção"*, 2022-09-01 , (ongoing), FCUL, Luis Peralta, Guiomar Evans

...

SCIENCE AND SOCIETY

MUTOM

Muon Tomography

Coordinator:
Sofia Andringa (50)

5 ***Researcher(s):***
Bernardo Tomé (15), Mário Pimenta (20), Paolo Dobrilla (50), Pedro Assis (2), Raul Sarmento (30)

1 ***Technician(s):***
Luís Lopes (15)

2 ***PhD Student(s):***
Luís Afonso (25), Pedro Teixeira (100)

1 ***Master Student(s):***
Magda Duarte (100)

4 ***Undergraduated Student(s) and Trainee(s):***
André Morais, Catarina Felgueiras, Isabel Alexandre, Yanhan Zhou

10 ***External collaborator(s):***
Bento Caldeira, José Borges, João Costa, João Matos, Lorenzo Cazon, Marco Alves Pinto, Mourad Bezzeghoud, Pedro Jorge, Rui Oliveira, Vanessa Pais

FTE External:
4.1 (PhD 1.7)

Executive summary

We work together with other institutions to explore muon tomography as a non-destructive imaging technique using the natural flux of atmospheric muons. In particular, we use muon telescopes made at LIP, from RPCs planes. We collaborate with Earth Science Institute (ICT), at the University of Évora to test the use of muography for sub-surface geophysical survey and with the Ciência Viva Center at Lousal (CCVL), installed at the location of an old mine and housing an underground mining gallery where we conduct a first end-to-end test of the technique, including the detector deployment outside laboratory conditions.

In 2021, the telescope was optimized at the Detectors Laboratory in Coimbra, while muographing a part of the building. The main methods for image reconstruction with this specific muon telescope were ready.

In 2022, the telescope was moved to the underground gallery in the Lousal mine, starting the geophysical survey. The first muograph showed an image compatible with the expectations from the Corona geological fault crossing the gallery, that we had established as main geological target.

Full analysis of this and other geophysical data is ongoing. The final geophysical analyses will be much more challenging, demanding to join the methods from particle physics and geophysics.

The first surveys of a human-made building and of subsurface geological structure will guide us in the search for applications of muon transmission tomography in follow-up projects, and in the upgrade of telescopes, analyses tools and methods, for new requirements.

MuTom

Overview

Muon tomography, a non-destructive imaging technique using the natural flux of atmospheric muons, has had a growing number of applications worldwide in the last decade. LIP has the expertise to contribute to the generalization of the technique locally and to help to establish it as a standard tool worldwide.

In 2021, we were funded by FCT to conduct an exploratory muography subsurface geophysical survey to demonstrate the potential of the technique with a well-known target.

The LouMu project has a short-term funding aimed at testing the capabilities of muography for sub-surface geophysical survey, which sets a relatively tight schedule for demonstrating the RPC-based telescope and our analyses techniques. In LouMu, the responsibilities are shared between LIP (detector and muography analysis), ICT-UÉvora (geophysical input and output) with the support of CCVLousal (logistics and outreach).

The team is geographically disperse, and coordination is key to keep the schedule. The telescope operation and upgrades are guaranteed by the team members at LIP in Coimbra; the analysis, including the RPC response and the image reconstruction, is done mostly at LIP in Minho and Lisbon; the simulation and geophysical analysis tools are shared between LIP in Lisbon and Évora; the communication effort is shared between all of those and CCVLousal.

We started by testing the detector and developing the methods while taking data in Coimbra – while muographing known structures in the LIP building; in mid-2022, the telescope was moved to the mining gallery in Lousal – to muograph also known but more challenging natural geological structures. The telescope already provides muographic images, we are now working on their interpretation.

Assessment of the past year: objectives vs. achievements

1. Muographic analysis of the Coimbra building

We had anticipated that extending the trigger to the full RPC area was needed to increase the field-of-view without a strong decrease in image resolution. Instead this was made possible by keeping the same trigger but exploring different combinations of planes to produce at the same time several images, with different field-of-view and resolutions.

Before moving to Lousal, more data were taken in different conditions, to enlarge the data-set for image reconstruction studies: with the detector in the same position but different inclinations to increase the field of view, or in close-by positions for 3D imaging of the same structures. The combinations of different planes allowed us to improve the resolution also in the central part of the field-of-view for the previously gathered data.

2. Moving to Lousal

In April 2022, the telescope was installed at the Lousal underground gallery, and started acquiring data soon after, with only small stops up to the end of the year. For safety reasons, the gas is fed and recovered outside the gallery. The gas operations are mostly handled by the Lousal team, while monitoring and DAQ control is done remotely from Coimbra and Lisbon, with improved tools. No changes were made in the normal operation: in particular the trigger settings from Coimbra are kept.

3. Muon tomography survey of Lousal

The presence of the geological fault became apparent after collecting around one month of data. The measured muon fluxes at the gallery are however different from our GEANT4 simulation, which includes the density of rock as sampled at the gallery and the fault with its expected position and size, slightly complicating the interpretations.

Two strategies have been implemented for the confirmation of the observations:

a) Using only real data, asymmetries in the measured fluxes have been identified as coming form the known location of the geological fault. At the end of the year the telescope was moved to another position, confirming the observation of a compatible structure from the same location.

b) For modeling, a fast simulation has been developed that allows to debug the GEANT4 implementation and to quantify the relative importance of the geological model and the muon propagation details.

In parallel, the ICT colleagues have collected data with independent geophysical methods. These are still being analysed. Those results will be useful as extra confirmation of the observation of the fault but also as extra samples to be used in a full combined geophysical analyses.

4. Communication and outreach

Already during data taking in Coimbra, we were publicly sharing the data collection and online image reconstruction. Now the telescope is in a Ciência Viva Center. The telescope is located in a closed storage room in the mine, which is visited only in organized events focusing on muography.

For other visits, a tablet carried by the visitor guides allows them to compare this telescope with a small prototype, which is visible in the visited part of the underground gallery and show the data as it is being collected.

Lines of work and objectives for next year

1. Operations at Lousal

The operation of the telescope at Lousal allow us to test the easiness of deployment of RPC muon telescopes in non-laboratory settings. We've identified the telescope is slightly too big and difficult to move, and measured a slight decrease in efficiency which may be related to the ingress of humidity over very long gas pipes. Both aspects will be reviewed and small upgrades are to be expected.

We will still collect data in more positions without major changes to the telescope design in itself, as guided by the muon and other geophysical data in order to conclude a first muon tomography geological survey test. Even after the survey is completed, we'll aim to keep the telescope at CCVLousal for outreach purposes and RPC R&D tests with focus on muography-like applications.

2. Muographic image analysis

We will continue to explore image reconstruction methods for a telescope with relatively low granularity in order to understand and optimize improvements for future telescopes. We'll focus on the optimization of number of planes vs number of channels per plane and on 3D image reconstruction.

This work will be based mostly in the data collected in Coimbra and related models. The methods will be readily used also at Lousal and as a test-case for similar applications of low depth image based analyses.

3. Muographic geological analysis

The analysis will proceed imaging the fault from different perspectives using only muography data; and with the development of the muon flux and transmission model allowing the extraction of the crossed depth.

At the same time, the ICT colleagues will analyse the seismic refraction and ground penetrating radar data, identifying independently the signatures of the geological fault and other discontinuities to include in our simulation model.

The final general goal is the comparison of the muography results with those from other methods, and their combination, in order to quantify the usefulness of muography in subsurface geophysics.

4. Preparation of future projects

The lessons from the Coimbra and Lousal data allow us already to start searching for future projects, either in geophysics or in large underground human-made structures. This will be a main focus for next year. While in 2022 we focused mostly on scientific seminars and conferences, in 2023 the communication should be generalized to other communities that are possible muography users. This will be done through a broad dissemination but also networking targeted at specific entities and communities at local and national level.

Medium-term (3-5 years) prospects

The results obtained in the Coimbra building and Lousal mine will be key to determine future follow-up projects. With the experience gathered in the present muographic surveys, the tools will be available to check the feasibility and interpret the results of new surveys in similar settings, ie imaging from underground (or within a building).

The telescope will be available for new applications, for which the RPC planes can be upgraded, mainly for lower gas consumption or better resolution. The dominant factor in the cost of new planes (or of a new telescope, which would also be relatively easy to build) is the number of electronics channels to be read out, which is now limited to 64 pixels per plane.

Other muon tomography applications (e.g. transmission tomography in volcanoes or even scattering tomography) are also possible but demand much more adaptations in terms of the telescope and the analyses methods. They can be considered for the longer term or if some pressing opportunity arises.

SWOT Analysis

Strengths

The RPC technology is versatile and we have the structure to be able to create new telescopes as needed. The group has developed analysis methods, is still motivated to improve them, and is also prepared to apply them in a diversity of scenarios.

Weaknesses

It is still not clear how useful the muography can be compared to other geophysical methods. That is exactly the point of the present exploratory funding, that will end in 2023. Soon we will know!

Opportunities

Muon tomography is still in a growing phase worldwide and our surveys at Coimbra and at Lousal are excellent bases for dissemination and for focused demonstration of the potential of muography for geophysics but also other applications.

Threats

It is difficult to secure funding for developing an already existing technique, unless it can be argued it is competitive with existing methods in a real case application. If we fail to find strong follow up projects based on the LouMu results, it will be difficult to maintain a focused activity.

MuTom

Publications

1 Article(s) in national journals

- *"Muografia e a sua primeira aplicação em Portugal, na Mina do Lousal"*, Teixeira, Pedro; Andringa, Sofia; Bezzeghoud, M. et al., Gazeta de Física, Volume 45 / Fascículo 3,

2 International Conference Proceedings

- *"Muography in the University and in the Museum "*, S. Andringa et al (MuTom Coll.), Proc. Muography 2021, 24-26 Nov. 2021, JAIS, vol. 2022, no. 1
- *"Muography for Underground Geological Surveys: Ongoing Application at the Lousal Mine (Iberian Pyrite Belt, Portugal) "*, P. Teixeira et al (MuTom Coll.), Proc. Muography 2021, 24-26 Nov. 2021, JAIS, vol. 2022, no. 1

1 Book(s)/Chapter(s)

- *"Resistive Plate Chambers in Muography "*, A. Giammanco, S. Andringa, E. Cortina Gil, and M. Tytgat, Muography - Exploring Earth's Subsurface with Elementary Particles, Eds. L. Olah, H. K. Tanaka, D. Varga, AGU

3 LIP Students Notes

- *"Debugging and performance testing of the DAQ board based on the MAROC ASIC for muon tomography"*, J. Francisco, LIP-STUDENTS-21-39
- *"Muography of a water-Cherenkov detector of the Pierre Auger Observatory"*, Catarina Felgueiras, Daniel António Sousa, LIP-STUDENTS-22-15
- *"On the effects of Slow-Control variables over the Lousal Resistive Plate Chamber Muon Telescope efficiency"*, André Morais, Yanhan Zhou, LIP-STUDENTS-22-27

Presentations

3 Oral presentations in international conferences

- Raul Sarmento: *"Muon tomography with resistive plate chambers for geological characterization"*, 2022-09-28, RPC 2022 - XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, Geneva, Switzerland
- Luís Lopes: *" Outdoor systems performance and upgrade "*, 2022-09-30, RPC 2022 - XVI Workshop on Resistive Plate Chambers and Related Detectors, CERN, Geneva, Switzerland
- Pedro Teixeira: *"Muography applied in Underground Geological Surveys: ongoing work at the Lousal Mine (Iberian Pyrite Belt, Portugal)"*, 2022-11-29, MedGU 2022 - Mediterranean Geosciences Uniun Anual Meeting, Marrakesch, Marocco

4 Oral presentations in national or international meetings

- Pedro Teixeira: *"Projeto LouMu – Muografia no Lousal"*, 2022-01-11, Jornadas ICT 2022, online
- Pedro Teixeira: *"Muon tomography at LIP"*, 2022-07-04, Third Joint Workshop IGFAE / LIP, Santiago de Compostela, Spain
- Pedro Teixeira: *"Muon tomography"*, 2022-07-08, Jornadas LIP 2022, Coimbra
- Pedro Teixeira:*"Muografia para Reconhecimento Geológico: aplicação em curso na Mina do Lousal (Faixa Piritosa Ibérica, Portugal)"*, 2022-11-29, 10th Spanish-Portuguese Assembly of Geodesy and Geophysics, Toledo, Spain

2 Poster presentations in national or international meetings

- *"Muography of a building"*, Magda Duarte, 2022-07-09, Jornadas LIP 2022, Coimbra
- *Muografia - Raios Cósmicos para análise de estruturas geológicas"*, Sofia Andringa, 2022-09-12, 4a Conf. Física dos Países de Língua Portuguesa, Praia, Cabo Verde

4 Student presentations in advanced training events

- Luís Afonso: *"Cosmic Rays Outreach"*, 2022-07-06, 7th LIP/IDPASC student workshop, Coimbra
- Pedro Teixeira: *"Muography for Underground Geological Surveys: ongoing application at the Lousal Mine (Portugal)"*, 2022-07-07, 7th LIP/IDPASC student workshop, Coimbra
- Daniel Sousa: *"Muography of a water-Cherenkov detector of the Pierre Auger Observatory"*, 2022-09-08, LIP Internship Program 2022, Braga, Portugal
- André Morais: *"Muon tomography from Coimbra to Lousal"*, 2022-09-08, LIP Internship Program 2022, Lisbon, Portugal

3 Seminars

- Pedro Teixeira: *"Muography and the Project LouMu"*, 2022-02-16, Seminário do Doutoramento em Ciências da Terra e do Espaço, ICT, Évora
- Sofia Andringa: *"Muography and the LouMu project"*, 2022-05-18, Seminários de Física da FCUL,
- Sofia Andringa: *"Muography and the LouMu project"*, 2022-05-19, LIP Seminars, Lisbon, Portugal

4 Outreach seminars

- Pedro Teixeira: *"Muografia e o Projeto LouMu"*, 2022-03-12, IPPOG Particle Physics Masterclasses 2022, Universidade de Évora
- Pedro Teixeira: *"Muões Cósmicos na Mina"*, 2022-07-23, Ciência Viva no Verão 2022, Lousal, Portugal
- Pedro Teixeira: *"Muões Cósmicos na Mina"*, 2022-07-30, Ciência Viva no Verão 2022, Lousal, Portugal
- Pedro Teixeira: *"Muografia e o Projeto LouMu"*, 2022-11-21, , Escola Secundária de Rio Tinto

Theses

2 PhD

- Pedro Teixeira: *"Tomografia de Muões com RPCs na Mina do Lousal"*, 2017-09-25, (ongoing), UÉvora, Lorenzo Cazon, Mourad Bezzeghoud and Bento Caldeira

- Luís Afonso: *"Raios Cósmicos: desenvolvimento de módulos de divulgação através design participativo"*, 2021-11-23, (ongoing), UP, Pedro Assis, Ana Delicado (ICS)

1 Master

- Magda Duarte: *"Development of high-resolution, three-dimensional muographies"*, 2022-09-30, (ongoing), UMinho, Raul Sarmento, Nuno Castro and Sofia Andringa

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Sofia Andringa (Mourad Bezzeghoud)		49.203 €	2021-10-15 / 2023-04-14	EXPL/FIS-OUT/1185/2021 / Muography as a new tool for geophysics

SCIENCE AND SOCIETY

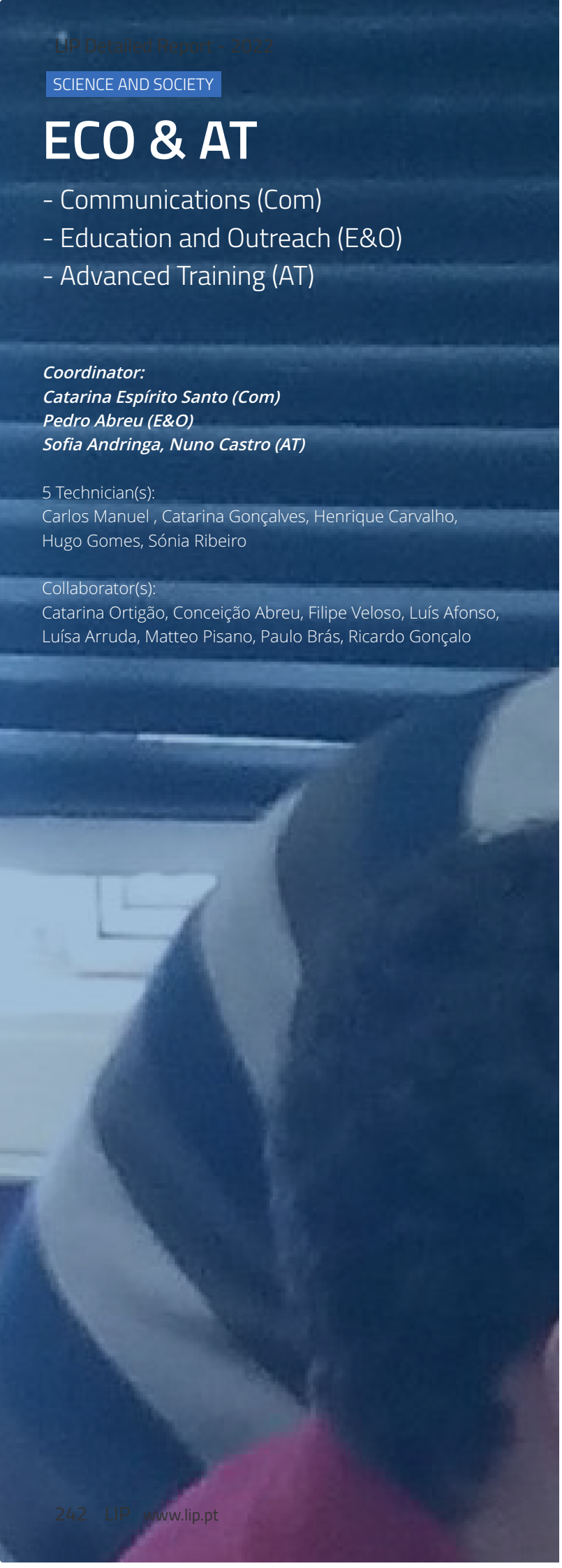
ECO & AT

- Communications (Com)
- Education and Outreach (E&O)
- Advanced Training (AT)

Coordinator:
Catarina Espírito Santo (Com)
Pedro Abreu (E&O)
Sofia Andringa, Nuno Castro (AT)

5 Technician(s):
Carlos Manuel , Catarina Gonçalves, Henrique Carvalho, Hugo Gomes, Sónia Ribeiro

Collaborator(s):
Catarina Ortigão, Conceição Abreu, Filipe Veloso, Luís Afonso, Luísa Arruda, Matteo Pisano, Paulo Brás, Ricardo Gonçalo



ECO & AT

Overview

This section is devoted to Communications (C), education and outreach (E&O), advanced training (AT). Such activities are an inseparable part of LIP's societal role. They are also essential for the recognition of the laboratory's impact and for the construction of its future.

The ECO & AT group implements, coordinates, and facilitates the laboratory's activities in these domains, encompassing all three LIP nodes. The overall strategy is define in LIP's Communications Strategy Document, which must be aligned with the lab's strategy and priorities, and implemented in close connection with the lab's management. Obviously, public outreach sessions, training events, or any form of dissemination of LIP's science are transversal activities. Its successful realization depend on the collaboration of all the groups at LIP.

Team Organization

The current comms strategy, which defines also the priority target audiences, currently dictates the organization of the team's activities in three closely related branches:

- COM: Institucional, strategic and science communications, both internal and external
- AT: Advanced training and outreach for university students in all cycles
- E&O: Education and outreach — the school community has always been the main focus; works together with COM and AT in strategic outreach events for other publics

Team members and collaborators

The team gathers competences in communication, graphic and web design, computing, as well as particle physics and related domains. We count on the collaboration of LIP Computing group members for website maintenance, databases, multimedia and more. A LIP researcher coordinates the AT activities, and graduate students may join the group in order to acquire experience in science communication. These colleagues participate in the group's weekly meetings and contribute with their ideas. Even with limited time availability, they are extremely helpful building up some critical mass in the team. However, the group's dedicated resources are clearly too scarce.This creates a permanent tension between routine tasks and any work in other projects, including the development of new ideas or the search for dedicated funding.

External collaborations and partnerships

LIP has several national and international partners in communication, outreach, support to education, and advanced training. At national level, we work in close collaborations with our associate universities and with several research units, both in training and in communication and outreach. We are partners of Agência Ciência Viva (CV), the Portuguese Physical Society (SPF) and have a close collaboration with several schools.
Internationally, LIP is part of (and currently co-chairs) the IPPOG Collaboration (International Particle Physics Outreach Group), the European Particle Physics CommunicationNetwork (EPPCN, fostering communication between CERN and its Member States), the CERN forum for high-school students and teachers activities, and the recently created UFPLP, the association of physicists in Portuguese speaking countries.

2022 Assessment and highlights

The year 2022 was marked by the start of LHC's Run 3 and the celebrations of the 10 years of the Higgs boson discovery's announcement (Higgs@10). It was also the year in which many of the events successively postponed due to pandemic restrictions finally took place. This resulted in an unusually busy event calendar.

Our plan for 2022 had two main goals:

- Recover the in-person realization of LIP's E&O and AT events and activities affected by the pandemic, while retaining the positive aspects found in more flexible hybrid models.
- Thrive to widen LIP's reputation — within the scientific community at large, and beyond that through the media as vectors.

While the first goal has been clearly achieved, the second and challenging goal has been hindered right from the start by two pandemic side-effects:

- The busy event calendar originated an excessive work burden assisting their organization: preparation and production of graphic materials of different types, promotion, organization of public sessions, reporting on the LIP news and social media, media communications.
- The return to a mainly in situ working model revealed a retreat in internal communications at different levels, which needed attention, namely through (limited) actions to promote socialization or to mediate the communication on existing practical difficulties. This affected mostly the (larger) Lisbon node.

As a positive side-effect of the pandemic work models, it is worth mentioning a noticeable improvement in the articulation between LIP nodes at several levels, from the co-supervision of students to the development of common projects or the preparation of outreach events. This was true also within the ECO and AT group.

The main events and actions are listed below.

For the LIP community & institutional

- Visit to CERN of the minister of Science of Science and Technology, accompanied by representatives of the national funding agency and Portuguese universities
- Participation in "Ciência 2022", the meeting of the national scientific community
- LIP's anniversary, with the invited talk "From the Higgs boson discovery to its long term future exploration" by Gregori Bernardi (LPNHE-Paris, IN2P3) followed by a drink+cake
- LIP/IDPASC student workshop: annual gathering of the LIP and IDPASC grant programme PhD students (which included a student picnic)
- Jornadas LIP: biennial scientific meeting of the LIP community
- Summer student barbecue and a few gatherings organized with LIP's students in Lisbon.

Public events

- International Day of Women and Girls in Science, celebrated with a public session in partnership with the astronomy and astrophysics institute IA and transmitted via Youtube; and with testimonial videos published on social media
- Celebration of the 10 year of the Higgs boson with the screening of the movie "Particle Fever" followed by a discussion, in three occasions and places along the year:
  - In the anniversary day, July 4, at IST, Lisbon
  - Within the European Researcher's Night programme at the main theatre hall in Coimbra
  - Following the opening of the ATLAS Week in Lisbon, with the participation of ATLAS members, including the spokesperson
- The HADES collaboration meeting was held in Coimbra and included a one-day public scientific workshop
- European Researcher's Night: held in-person in the three towns where LIP is present (Braga, Coimbra, Lisbon), integrated in the official celebration of the event in each town
- The ATLAS week in Lisbon included one more public session: a Universal Science event hosted by Steve Goldfarb (IPPOG/ATLAS) and with a panel of scientists.

Activities for the school community

- IPPOG's International Masterclasses in Particle Physics, back to in-person mode, took place in a dozen sites all over the country and gathered over a thousand participants.
- On LIP's anniversary, an activity with high-school students happened simultaneously in the three LIP nodes: a pilot-run of the new Masterclass based on Auger data, developed at LIP.
- The Ciência Viva Summer internships were held in at LIP-Lisboa, hosting eight high-school students for two weeks.
- CERN teachers' programme in Portuguese language was held in-person at CERN, with 48 participants. Besides the 20 Portuguese + 20 Brazilian, the school hosted teachers from all the other Portuguese language countries, for the second time in its history, with the support of Instituto Camões.
- LIP is the scientific partner of several Science Clubs/Ciência Viva clubs in schools. Activities of different kinds were developed with these groups:
  - talks on cosmic rays and particle physics

Contents, publications, media, and communication support activities

• Around 70 news items published in LIP's public web page, close to 15% of them issuing press releases or communications sent directly to journalists

• Over 200 posts (close to 100 stories) on Instagram, Facebook, Twitter, LinkedIn and Youtube (total number of followers increased from 5000 to 6500 along the year

• Collaboration with CERN/EPPCN and relations with the media

• Produced a small exhibit about LIP and particle physics that was shown in a shopping mall in Coimbra (eight 200x50 cm panels plus the LIP spark chamber)

• Provided the Portuguese translation of CERN's Higgs@10 poster series, available online

• Preparation of LIP's yearly reports: the detailed report for the general assembly and the internacional advisory board, and the public report (printed+online versions, illustrated)

• It was not possible to publish neither the LIP-News bulletin nor the internal newsletter

• Support to the organization of events and other communication needs by the groups

• Training in science communication:

  ◦ Several LIP students collaborated with the ECO group throughout the year or volunteered to participate in public events.

  ◦ A hands-on session on speaking in public was proposed to the participants in the LIP Internship Programme during the tutorials week.

• Plans to produce an institucional video, a welcome kit for news members and a traveling exhibition were postponed due to lack of human resources.

• There were attempts to reinforce the social component of LIP's internal life, in particular in regular internal meetings — with limited success, mostly due to too tight schedules and some resistance to change.

Advanced Training events

• The Laboratory permanently hosts close to 100 doctoral, master and bachelor students, in a close connection with its associated universities,namely in Lisboa, Coimbra and Minho. The number of students has been growing in the last couple of years. Events such as the LIP/IDPASC student workshop (see above) or the periodic graduate student survey are paramount for the integration and follow-up of this community.

• LIP's Internship Program is the lab's flagship AT program. Over 50 students participated in the 2022 edition, in the three LIP nodes. The program counted on the broad participation of LIP researchers, who served as project supervisors, delivered tutorials and lectures, guided topical discussions, and attended and contributed to the final workshop. The program starts with an introduction week in July (lectures and hands-on tutorials, complemented with thematic discussions in small groups) and ends with a two-day final workshop in September where students presented their work. These common activities were held in hybrid mode. In between, the participants carried out their projects, integrated in LIP's research groups. Most of the projects contributed final papers, published on the LIP website. The remote format and tools further facilitated the participation of students and co-supervisors from abroad. Several social and discussion activities took place throughout the Summer

• 7th Mini-school in particle and astroparticle physics, co-organized by LIP and CFTP, was held in hybrid mode (remote lectures and in-person hand-on sessions) and gathered around 20 undergraduate students from several universities

• 7thLIP/IDPASC student workshop (see above)

• 1st Prototera PhD Student Workshop: meeting of the PhD students and supervisors in the Prototera PhD grant programme, in which all students are invited to present their work.

• Data Science school and symposium, 27-30 June, in Coimbra, an event series focused on stimulating synergies between fundamental research and industry in data science.

• Physics at the LHC course: online from March to May, in a total of 20 lectures. X students gave a final presentation that served as final evaluation, valid for ECTS credits at IST.

• LIP Seminars: regularly held at the three LIP nodes, mostly in hybrid mode

• LIP regularly participates in events organized by physics student associations.

• FCT's PhD grants programs: during 2022, two calls were open for the PT-CERN programs (both domains: particle and astroparticle physics, and technologies associated with the Portuguese participation at CERN) and one call for the ProtoTera program (multidisciplinary training in medical sciences, technology and physics).

2023: Prospects and plans

In each of our three branches of activity, Communication (COM), Education and Outreach (E&O) and Advanced Training (AT) we define two complementary goals:

COM

• Consolidate and enlarge LIP's reputation, starting from our closest stakeholders and partners (scientific, academic, political) and opening towards the broad science-related

community, through a strategy based on the media (traditional and social) as vectors and on seeking to establish link with player in the scientific, cultural and artistic scene.

• In both external and internal communications, consolidate or enhance some of the existing channels and activities (namely magazine, digital newsletters, social media, new member welcome kit) and develop some of those still in the waiting list (institutional video, open day, traveling exhibition, community-building tools).

E&O

• Successfully carry on our regular yearly program for the school community, pursuing with its consolidation after the pandemic crisis, with emphasis in the flagship activities: IPPOG's international masterclasses in particle physics and the CERN school for teachers in Portuguese language.

• Boost the ongoing developments towards more interactive, hands-on and participative models of relation between science and society, and towards wider publics.

AT

• Keep LIP's regular offer of advanced training activities for the different university cycles, in particular our flagship LIP's Intership Program during the Summer, while taking into account the research projects and internships students are increasingly requested to carry on also during the academic year.

• As for LIP's graduate students, conduct the period survey to assess the progression of their work, supervision quality, training opportunities, working conditions and social integration; develop a plan for improvement based on the analysis of the results.

SWOT Analysis

Strengths

Broad set of backgrounds, experience and enthusiasm of team members. Contributions from other people and groups in the lab.

Weaknesses

Very limited human and material resources hinder the ability to demonstrate impact. Lack of critical mass for strategical discussions.

Opportunities

The existing knowledge, ideias and network of contacts could open opportunities for new projects and collaborations (local, national or european) able to attract dedicated funding.

Threats

The lack of HR to develop efforts such as designing and writing proposals for projects and collaborations threatens to keep us trapped in a low resources, low impact situation.

ECO & AT

Publications

31 LIP Students Notes

- *"Study of a Scintillant Fibers Microdosimeter on Different Radiation Environ- ments using FLUKA Code"*, Madalena Gamboa, LIP-STUDENTS-21-38
- *"Debugging and performance testing of the DAQ board based on the MAROC ASIC for muon tomography"*, J. Francisco, LIP-STUDENTS-21-39
- *"Probing the cosmic ray composition with SWGO"*, Afonso Guerreiro, LIP-STUDENTS-22-01
- *"Anomaly Detection in all hadronic boosted final states"*, Junda Tong, LIP-STUDENTS-22-02
- *"Identification of kaons using Neural Networks in COMPASS and AMBER experiments at CERN"*, Guilherme Amaral, LIP-STUDENTS-22-28
- *"First sudies with SND@LHC"*, Bruno Semião, Pedro Figueiredo, LIP-STUDENTS-22-03
- *"Sky Watching in Gamma Rays: Searching the Universe for High Energy Processes"*, Miguel Godinho, José Bernardo Ferreira, LIP-STUDENTS-22-04
- *"Building a QCD parton shower"*, Diogo Costa, Ana Carolina Ribeiro, LIP-STUDENTS-22-05
- *"Study of central and exclusive production of tau-tau pairs at LHC"*, Alexandre André, Pedro Batista, LIP-STUDENTS-22-06
- *"First Measurements with a Scintillating Fiber Microdosimeter"*, Beatriz Fernandes, LIP-STUDENTS-22-08
- *"Probing the vaccum with di-Higgs production"*, Diogo Pires Nunes, Francisco Casalinho, LIP-STUDENTS-22-09
- *"Measurement of B+ and B0 s meson cross sections in pp collisions at the LHC"*, Simão Costa, Jean Luo, LIP-STUDENTS-22-10
- *"Development of Hybrid 10B - RPC based neutron detectors"*, Carolina Oliveira Fernandes, LIP-STUDENTS-22-11
- *"Aplicação de métodos de Machine Learning e Deep Learning na análise de batimentos Cardíacos"*, Sandra Silva Taborda Mamede, LIP-STUDENTS-22-07
- *"Direct detection of dark matter at LUX-ZEPLIN"*, Mariana Sofia Rasteiro Letra, Paulo Pires, Pedro Barata de Tovar Caetano de Sá, LIP-STUDENTS-22-12
- *"nRPC simulation with TOPAS"*, Carolina Felgueiras, LIP-STUDENTS-22-13
- *"Search for New Phenomena in the Top quark sector using Anomaly Detection"*, Inês Pinto, Joan Kladnik, LIP-STUDENTS-22-14
- *"Muography of a water-Cherenkov detector of the Pierre Auger Observatory"*, Catarina Felgueiras, Daniel António Sousa, LIP-STUDENTS-22-15
- *"Unravelling time variability in solar activity"*, Rafael Parente, LIP-STUDENTS-22-16
- *"Application of a Data Driven Method to Isotopes Identification in the AMS"*, Diogo Lemos, LIP-STUDENTS-22-17
- *"High-precision timing detectors for the HL-LHC"*, Beatriz Amorim, LIP-STUDENTS-22-18
- *"Geo-neutrinos"*, Margarida Ferreira, LIP-STUDENTS-22-19
- *"Performance of microdosimetric detectors using Monte-Carlo"*, Filipe Ficalho, LIP-STUDENTS-22-20
- *"Study of new scintillator samples for future detectors"*, Christian Tanga, LIP-STUDENTS-22-21
- *"Target preparation at FCUL"*, Margarida Paulino, Raquel Nunes, LIP-STUDENTS-22-22
- *"Radiation ""bombs"" in amyloids"*, Hannah Scharff, Maria Teixeira Rebouta, LIP-STUDENTS-22-23
- *"Upgrade of the ATLAS Tile Calorimeter High Voltage System"*, Tiago Prates da Costa, LIP-STUDENTS-22-24
- *"Measuring The Sky"*, Özgür Özer, LIP-STUDENTS-22-25
- *"New Plastic Scintillators for future Light-based detectors"*, Pedro Mendes, LIP-STUDENTS-22-26
- *"On the effects of Slow-Control variables over the Lousal Resistive Plate Chamber Muon Telescope efficiency"*, André Morais, Yanhan Zhou, LIP-STUDENTS-22-27
- *"Distinguishing decay processes for Heavy Neutral Leptons with Machine Learning at SHiP"*, Rui David Martinho Santos, LIP-STUDENTS-22-30

Presentations

1 Oral presentation(s) in international conference(s)

- Pedro Abreu for the IPPOG Collaboration: *"Public Engagement in High Energy Physics"*, 2022-01-12, 30th International Symposium on Lepton-Photon interactions at high energies, Univ. Manchester, UK (online via Zoom)

Around 50 Outreach seminar(s) by LIP researchers in schools and other settings

Funding

PI (Co-PI)	Source	Amount	Dates	Project / Description
Catarina Espírito Santo		23.500 €	2021-01-01 to 2025-12-31	EPPCN-KE2826 -Amend / EPPCN Agreement Amendment
Pedro Abreu		5.000 €	2022-05-01 to 2022-11-30	CV/03-2022 / CV/03-2022 - 14ª Escola de Professores no CERN em Língua Portuguesa

Summary Tables

Funding

Human Resources

Scientific Output

FCT Fundings (part1)

Project	FA	polo	Group	PI	Amount	StartDate	EndDate
UIDB/50007/2020	FCT	LIPL	LIP - Geral	Mário Pimenta	2 370 140 €	2020-01-01	2023-12-31
UIDP/50007/2020	FCT	LIPL	LIP - Geral	Mário Pimenta	722 000 €	2020-01-01	2023-12-31
LA/P/0016/2020	FCT	LIPL	LIP - Geral	Mário Pimenta	4 490 705 €	2021-01-01	2025-12-31
CERN/FIS-PAR/0010/2021	FCT	LIPL	ATLAS	Patricia Conde, Nuno Castro	165 000 €	2021-09-01	2023-08-31
CERN/FIS-PAR/0026/2021	FCT	LIPC	ATLAS	Ricardo Gonçalo, Agostinho Gomes	192 672 €	2021-10-01	2023-09-30
CERN/FIS-INS/0029/2021	FCT	LIPL	CMS	João Varela, Michele Gallinaro	200 000 €	2021-09-16	2023-09-15
CERN/FIS-PAR/0005/2021	FCT	LIPL	CMS	Michele Gallinaro, Nuno Leonardo	185 000 €	2021-11-01	2023-10-31
PTDC/FIS-PAR/1214/2021	FCT	LIPL	CMS	Jonathan Hollar, Michele Gallinaro	248 366 €	2022-01-01	2024-12-31
CERN/FIS-PAR/0024/2019	FCT	LIPL	Pheno	Guilherme Milhano, Liliana Apolinário	90 000 €	2020-07-01	2022-06-30
CERN/FIS-PAR/0010/2019	FCT	LIPL	Pheno	Pietro Faccioli	20 000 €	2020-09-01	2022-08-31
CERN/FIS-PAR/0037/2021	FCT	LIPC	Pheno	António Onofre, Miguel Fiolhais	45 000 €	2021-11-15	2023-11-14
EXPL/FIS-PAR/0905/2021	FCT	LIPL	Pheno	Liliana Apolinário, Carlota Casas	49 464 €	2021-12-01	2023-05-31
EXPL/FIS-PAR/1195/2021	FCT	LIPL	Pheno	Grigorios Chachamis, João Nuno Pires	49 922 €	2022-01-17	2023-07-16
CERN/FIS-PAR/0032/2021	FCT	LIPL	Pheno	Guilherme Milhano, Liliana Apolinário	80 000 €	2022-07-01	2024-06-30
CERN/FIS-PAR/0035/2021	FCT	LIPL	FCC	João Nuno Pires, Ricardo Gonçalo	15 000 €	2022-04-01	2024-03-31
CERN/FIS-PAR/0016/2021	FCT	LIPL	P&QCD	Catarina Quintans, Carlos Azevedo	120 000 €	2021-10-01	2023-09-30
EXPL/FIS-NUC/0364/2021	FCT	LIPL	NUC-RIA	Daniel Galaviz, Alberto Blanco	49 874 €	2021-10-15	2023-04-14
CERN/FIS-PAR/0009/2021	FCT	LIPL	NUC-RIA	Daniel Galaviz, A.M. Sanchez-Benitez	20 000 €	2022-04-01	2024-03-31
2022.06730.PTDC	FCT	LIPL	NUC-RIA	Jorge Sampaio, José Pires Marques	46 485 €	2023-01-01	2024-06-30
IF/00898/2015	FCT	LIPL	NPStrong	Gernot Eichmann	22 382 €	2017-04-01	2022-03-31
CERN/FIS-PAR/0023/2021	FCT	LIPL	NPStrong	Alfred Stadler, Gernot Eichmann	70 000 €	2022-03-15	2024-03-14
CERN/FIS-PAR/0007/2021	FCT	LIPL	AMS	Fernando Barão, Luisa Arruda	45 000 €	2021-12-01	2023-11-30
CERN/FIS-PAR/0012/2021	FCT	LIPL	Auger	Pedro Assis, Ruben Conceição	135 000 €	2021-10-01	2023-09-30
CERN/FIS-PAR/0020/2021	FCT	LIPL	Auger	Ruben Conceição, Pedro Assis	70 000 €	2021-10-01	2023-09-30
PTDC/FIS-PAR/4300/2020	FCT	LIPL	SWGO	Mário Pimenta, Ruben Conceição	249 585 €	2021-05-15	2024-05-14
IF/00877/2015/CP1311/CT0002	FCT	LIPC	DarkMatter	Cláudio Silva	50 000 €	2016-11-01	2022-02-28
PTDC/FIS-PAR/2831/2020	FCT	LIPC	DarkMatter	Isabel Lopes, Francisco Neves	249 948 €	2021-06-01	2024-05-31
IF/00248/2015/CP1311/CT0001	FCT	LIPL	Neutrino	Valentina Lozza	50 000 €	2017-01-01	2022-03-31
CERN/FIS-PAR/0014/2021	FCT	LIPL	Neutrino	José Maneira, Nuno Barros	90 000 €	2021-09-01	2023-08-31
PTDC/FIS-PAR/2679/2021	FCT	LIPL	Neutrino	Nuno Barros, Valentina Lozza	231 005 €	2021-12-01	2024-11-30
CERN/FIS-INS/0028/2021	FCT	LIPL	SHiP	Nuno Leonardo, Alberto Blanco	40 000 €	2022-03-04	2024-03-03

FCT Fundings (part2)

Project	FA	polo	Group	PI	Amount	StartDate	EndDate
CERN-FIS-INS-0009-2019	FCT	LIPC	RPC	Alberto Blanco, Paulo Fonte	70 000 €	2020-07-01	2022-06-30
CERN/FIS-INS/0006/2021	FCT	LIPC	RPC	Alberto Blanco, Paulo Fonte	70 000 €	2022-07-01	2024-06-30
EXPL/FIS-NUC/0538/2021	FCT	LIPC	nDet	Luís Margato, Andrey Morozov	49 957 €	2022-01-01	2023-06-30
PTDC/FIS-NUC/3933/2021	FCT	LIPC	GasDet	João Veloso, Filipa Borges	62 910 €	2022-01-01	2024-12-31
CERN/FIS-INS/0026/2019	FCT	LIPC	LqXe	Vitaly Chepel, João Veloso	35 000 €	2020-11-01	2022-10-31
CERN/FIS-INS/0013/2021	FCT	LIPC	LqXe	Vitaly Chepel, João Veloso	35 000 €	2022-11-01	2024-10-31
CERN/FIS-TEC/0017/2021	FCT	LIPC	ORimag	Paulo Crespo, Patrícia Gonçalves	90 000 €	2022-01-01	2023-12-31
EXPL/FIS-PAR/0333/2021	FCT	LIPC	i-Astro	Rui Curado Silva, Jorge Maia	49 966 €	2022-01-01	2023-06-30
INCD 01/SAICT/2016 - nº 022153	FCT	LIPL	GRID	Jorge Gomes	223 000 €	2017-07-18	2022-12-21
CERN/FIS-COM/0018/2021	FCT	LIPL	GRID	João Pina, Mário David	29 999 €	2022-03-21	2024-03-20
POCI-05-5762-FSE-000438	FCT	LIPL	GRID	Jorge Gomes, Mário David	19 999 €	2022-12-01	2023-12-31
EXPL/EME-NUC/1311/2021	FCT	LIPL	LOMaC	Rute Pedro, António Pontes	49 964 €	2022-01-01	2023-06-30
PTDC/FIS-MAC/2045/2021	FCT	LIPM	SimBigDat	Nuno Castro	18 750 €	2022-01-01	2024-12-31
CERN/FIS-COM/0004/2021	FCT	LIPM	SimBigDat	Miguel Romão, Inês Ochoa	30 000 €	2022-02-01	2024-01-31
EXPL/FIS-OUT/1185/2021	FCT	LIPL	MuTom	Sofia Andringa, Mourad Bezzeghoud	49 203 €	2021-10-15	2023-04-14

Other Funding Agencies

Project	FA	polo	Group	PI	Amount	StartDate	EndDate
Fundação La Caixa - Inês Ochoa	LaCaixa	LIPL	ATLAS	Inês Ochoa	297 900 €	2020-07-01	2023-11-27
824093 - STRONG-2020	EU	LIPL	Pheno	Guilherme Milhano	188 500 €	2019-06-01	2023-11-30
835105 - YoctoLHC	EU	LIPL	Pheno	Guilherme Milhano	399 062 €	2019-10-01	2025-09-30
MuCol - Proposal 101094300	EU	LIPL	FCC	Michele Gallinaro	40 000 €	1000-01-01	9999-12-31
aAmuse - Project 101006726	EU	LIPL	FCC	Michele Gallinaro	115 000 €	2022-01-01	2025-12-31
POCI-01-0247-FEDER-039808	EU	LIPC	RPC	Paulo Fonte	161 255 €	2019-06-17	2022-04-16
101004761 AIDAinnova	EU	LIPC	RPC	Alberto Blanco	20 000 €	2021-04-01	2025-03-31
LISBOA-01-0247-FEDER-045904	EU	LIPC	ORimag	Paulo Crespo, Patrícia Gonçalves	222 004 €	2020-01-01	2023-06-30
LISBOA-01-0247-FEDER-045904	EU	LIPC	ORimag	Paulo Crespo, Patrícia Gonçalves	222 004 €	2020-01-01	2023-06-30
ESA: 1-7560/13/NL/HB	ESA	LIPL	SpaceRad	Patrícia Gonçalves	300 000 €	2014-02-18	2022-03-31
ESA: 4000137865/22/ES/JD	ESA	LIPL	SpaceRad	Patrícia Gonçalves	75 000 €	2022-04-01	2025-03-31
871158-AHEAD 2020	EU	LIPC	i-Astro	Rui Curado Silva	30 000 €	2020-03-02	2024-12-01
4000136945 GLOSS	ESA	LIPC	i-Astro	Rui Curado Silva, Jorge Maia	106 153 €	2021-06-01	2024-06-30
EOSC-synergy grant 857647	EU	LIPL	GRID	Jorge Gomes	433 000 €	2019-09-01	2022-10-31
LISBOA-01-0247-FEDER-045924 / POCI-01-0247-FEDER-045924	EU	LIPL	GRID	Jorge Gomes	249 561 €	2020-03-31	2023-03-31
EUROCC	EU	LIPL	GRID	Jorge Gomes, João Pina	347 051 €	2020-09-01	2022-12-31
EGI-ACE	EU	LIPL	GRID	Jorge Gomes	196 238 €	2021-02-01	2023-08-31
EOSC-Future	EU	LIPL	GRID	Jorge Gomes, João Pina	160 375 €	2022-01-01	2024-12-31
interTwin (ID:101058386)	EU	LIPL	GRID	Jorge Gomes	342 812 €	2022-06-01	2025-05-31
AI4EOSC	EU	LIPL	GRID	Mário David	350 250 €	2022-06-01	2025-05-31
DT-GEO	EU	LIPL	GRID	Jorge Gomes	542 875 €	2022-06-01	2025-05-31
iMagine	EU	LIPL	GRID	Mário David, Jorge Gomes	222 125 €	2022-06-01	2025-05-31
EuroCC 2	EU	LIPL	GRID	Jorge Gomes, João Pina	146 000 €	2023-01-01	2025-12-31
LISBOA-01-0247-FEDER-045924 / POCI-01-0247-FEDER-045924	EU	LIPL	GRID	Jorge Gomes	249 561 €	2020-03-31	2023-03-31
853566 - FARE	EU	LIPL	SPAC	Joana Gonçalves-Sá	1 499 844 €	2020-10-01	2025-09-30
101100653 - FARE_AUDIT	EU	LIPL	SPAC	Joana Gonçalves-Sá	150 000 €	2022-12-01	2024-05-31
UC/INOVC + / MonNest	UC	LIPC	CCMC	Francisco Neves	4 750 €	2022-10-03	2023-06-30
EPPCN-KE2826 -Amend	CERN	LIPL	ECO	Catarina Espírito Santo	23 500 €	2021-01-01	2025-12-31
CV/03-2022	CVIVA	LIPL	ECO	Pedro Abreu	5 000 €	2022-05-01	2022-11-30

Human Resources on research

Group	FTE	Heads(*)	Researchers	Technicians	PhD	Master	Undergrad	Additional	External
ATLAS	20.7	39	16	5	7	11	19	0	9
CMS	13.1	18	8	2	6	2	9	0	8
Pheno	23.0	36	15	2	8	11	7	0	17
FCC	2.0	11	8	0	1	2	1	0	0
P&QCD	4.0	5	3	1	0	1	3	0	3
HADES									
NUC-RIA	12.3	20	7	2	5	6	6	0	3
NPStrong	4.8	9	5	0	3	1	2	0	2
AMS	3.2	5	4	0	1	0	3	0	2
Auger	10.9	21	10	4	5	2	2	0	2
SWGO	7.2	18	11	4	3	0	5	0	3
DarkMatter	9.3	15	9	0	1	5	6	0	1
Neutrino	6.8	14	9	1	2	2	4	0	1
SHiP/SND@LHC	2.9	10	6	2	1	1	4	0	0
RPC	5.4	18	9	7	1	1	3	0	2
nDet	3.2	9	6	2	0	1	3	0	1
GasDet	4.9	8	6	1	1	0	0	0	0
LqXe	0.8	3	3	0	0	0	0	0	0
ORimag	7.3	14	7	0	2	5	0	0	1
Dosimetry	13.1	25	7	0	9	9	7	0	10
SpaceRad	4.3	8	4	0	0	4	2	0	2
i-Astro	7.4	14	7	2	0	5	4	0	3
GRID	12.9	16	4	12	0	0	0	0	5
SPAC	8.0	10	4	4	2	0	3	0	7
DetLab	2.6	4	1	3	0	0	0	0	0
Workshop	3.5	5	1	4	0	0	0	0	0
e-CRLab		6	1	4	1	0	0	0	3
LOMaC	2.4	9	5	2	2	0	3	0	2
TagusLIP		2	1	1	0	0	0	0	5
CCMC									
SimBigDat									
RHE	2.3	7	5	0	0	2	0	0	2
MuTom	4.1	10	6	1	2	1	4	0	10
Total	**194.5**	**262**	**98**	**39**	**53**	**72**	**113**	**0**	**91**

Scientific output (part1)

Group	Papers in Ref. Jrns. with Direct Contribution	Other Papers in Refereed Journals	Proceedings, Preprints and Notes	Books, Reports, Proposals and Software Tools	Presentations in Int. Conf.
ATLAS	3	51	12	0	11
CMS	6	69	17	0	7
Pheno	11	11	5	0	4
FCC	0	0	1	0	0
P&QCD	1	2	2	0	3
HADES	1	1	0	0	2
NUC-RIA	9	9	4	0	5
NPStrong	3	3	0	0	9
AMS	2	3	2	0	0
Auger	3	7	5	1	4
SWGO	6	6	7	0	3
DarkMatter	1	5	15	0	5
Neutrino	3	6	1	0	1
SHiP	2	3	2	1	0
RPC	2	2	0	0	8
nDet	1	1	1	0	1
GasDet	4	5	0	0	1
LqXe	0	0	0	0	2
ORimag	0	0	0	0	4
Dosimetry	1	1	2	0	2
SpaceRad	4	4	2	0	1
i-Astro	1	1	1	0	4
GRID	0	0	17	3	11
SPAC	0	0	0	2	13
TagusLIP	0	0	0	0	0
CCMC	0	0	1	0	1
SimBigDat	2	2	2	0	2
RHE	0	0	0	0	0
MuTom	0	0	5	1	3
TOTAL	**63**	**189**	**104**	**8**	**99**

Scientific output (part2)

Group	Other Presentations	PhD	Master	Events
ATLAS	24	0	1	1
CMS	34	0	0	0
Pheno	7	1	6	0
FCC	1	0	0	0
P&QCD	2	0	1	0
HADES	0	0	0	1
NUC-RIA	2	0	1	0
NPStrong	2	0	0	0
AMS	13	2	0	0
Auger	8	0	1	0
SWGO	12	0	0	0
DarkMatter	6	0	4	0
Neutrino	1	1	1	1
SHiP	11	0	0	0
RPC	1	0	0	0
nDet	2	0	0	0
GasDet	0	0	0	0
LqXe	0	0	0	0
ORimag	3	0	3	0
Dosimetry	4	0	1	0
SpaceRad	17	0	1	0
i-Astro	2	0	2	0
GRID	11	0	0	6
SPAC	23	0	1	2
TagusLIP	0	0	0	0
CCMC	1	0	2	0
SimBigDat	1	0	1	1
RHE	0	0	1	0
MuTom	13	0	0	0
TOTAL	**185**	**4**	**26**	**12**

Scientific output - Summary for Public Report

	Particle Physics	Astroparticle Physics	Detectors and Applications	Computing	Total	
Papers in Ref. Jrns. with Direct Contribution	34	17	13	2	63	Jrn-Dir (published or accepted)
Other Papers in Refereed Journals	146	30	14	2	189	Jrn-Dir, Jrn-Int-Rev, Jrn-Ind (published or accepted)
Proceedings, Preprints and Notes	41	32	15	19	104	Proc-Int, Proc-Nat, Col-Note, Int-Note, Preprint, LIPstud (published or accepted)
Books, Reports, Proposals and Software Tools	0	2	1	5	8	Inst-Rep, Prop, DigitalTool, Bks (published or accepted)
Presentations in Int. Conf.	40	13	24	26	99	Oral-Int, Poster-Int
Other Presentations	72	48	49	35	190	all except Oral-Int, Poster-Int, Stud-AdvTrain, Coll-Mtg
Concluded Master Theses	9	6	10	2	26	(finished this year)
Concluded PhD Theses	1	3	0	0	4	(finished this year)
Organized Events	2	1	0	9	12	all

- **Particle Physics:**
  - Research Lines: LHC experiments and phenomenology; Structure of matter
  - Groups: ATLAS; CMS; Pheno; FCC; P&QCD; HADES; NUC-RIA; NPStrong
- **Astroparticle Physics:**
  - Research Lines: Cosmic rays; Dark matter and neutrino
  - Groups: AMS; Auger; SWGO; DarkMatter; Neutrino; SHiP
- **Detectors and Applications:**
  - Research Lines: Detector development for particle and nuclear physics; Instruments and methods for biomedical applications; Radiation environment studies and applications for space missions
  - Groups: RPC; nDet; GasDet; LqXe; ORimag; Dosimetry; SpaceRad; i-Astro
  - Extra Groups: RHE; MuTom; LOMaC; TagusLIP; e-CRLab; Workshop; DetLab; CCMC
- **Computing:**
  - Research Lines: Scientific Computing
  - Groups: GRID; SPAC
  - Extra Group: SimBigDat

Training Courses

Name	Training Entity	Start Date	End Date	Place / Cost	Certification	Comment	Training Type / Hours	Trainees
Introdução à utilização e proteção dos dados pessoais	external	2021-03-24	2023-04-16	online / 0 €	Certif. Qualificações	Formação modular Profissional	Other Trainings / 25 H	João Pedro Santos
Plano de negócio – criação de micronegócios - ativos - 6ª edição	external	2022-02-08	2023-02-28	online / 0 €			/ 25H	Leonor Coimbra
Segurança e Saúde no trabalho	external	2022-02-10	2022-02-10	Online / 221,40€	Yes	SHT	/ 2	Cláudio Silva, Elisabete Neves, Filipe Veloso, Helmut Wolters, Hugo Simões, Joana Mingacho, João Carlos Silva, João Saraiva, José Escada, Nuno Carolino, Paulo Brás
Inteligência Emocional	external	2022-02-21	2022-03-07	Online / 0 €	Certif. Qualificações	Formação Profissional	/ 25	Natália Antunes
Segurança e Saúde no trabalho	external	2022-04-06	2022-04-06	Online / 221,40€	Yes	SHT	/ 2	Alberto Blanco, Alexandre Lindote, Andrey Morozov, Carlos Silva, Francisco Neves, Jorge Moreira, Luís Lopes, Luís Margato, Margarida Rodrigues, Nuno Filipe Silva Dias, Orlando Cunha, Rui Alves, Rui Curado Silva
Como emitir o Relatório Único no ERP PRIMAVERA	external	2022-04-07	2022-04-07	Online / 119,56€			/ 1	Cláudia Delgado, Margarida Rodrigues
Organização de eventos nacionais e internacionais	external	2022-05-02	2022-05-20	Online / 0 €	Certif. formação profissional	Formação Profissional	/ 25	Natália Antunes, Ofélia Janeiro
Workshop Horizonte Europa - Preparação de propostas - elaboração de orçamento	ANI	2022-07-19	2022-07-19	ANI - presencial / 0 €	Sem certificação	Não conferente de grau	/ 6	Natália Antunes
Social media	IST	2022-12-20	2022-12-21	IST, Lisboa / 0 €	No	Professional technical training	/ 6	Catarina Espírito Santo
Mini-School on electronics design using Altium	LIPC	2023-01-30	2023-02-07	Online + LIP Coimbra (hands on) + LIP Lisboa (hands on) / 0 €		Técnica (Interna)	/ 16	António Caramelo, Filipe Martins, Francisco Neves, Gil Ramos Madeira, Helena Santos, Henrique Carvalho, João Gentil, José Aparício, José Carlos Nogueira, José Sousa, Luís Gurriana, Maria Miguel, Nuno Barros, Nuno Carolino, Orlando Cunha, Rui Fernandez, Tatiana Mendes
Comunicação inclusiva e sensível ao género	UC	2023-02-27	2023-02-27	iii-UC (Casa Costa Alemão - Polo 2 UC) / 0 €	Yes	Projeto GendER@UC iiiUC, Programa EEAGrants	Professional Technical Trainings / 4	Margarida Rodrigues

Awards

- ***Eduardo Ferreira: "McCartor Fellowship Award 2022",*** 2022-09-09
- ***Gabriela Oliveira: "Gulbenkian "Novos Talentos" grant"***, 2022-11-04
- ***Pedro Abreu: "Prémio Ciência Viva Educação 2022"***, 2022-11-24
- ***Pedro Mendes Pereira: "UMinho Award for Initiation in Scientific Research 2022"***, 2022-12-13
- ***Catarina Felgueiras: "UMinho Award for Initiation in Scientific Research 2022"***, 2022-12-13
- ***Maria Ramos: "Univ. Minho best 2022 PhD thesis award "***, 2022-12-31

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA
EXPERIMENTAL DE PARTÍCULAS