LIP detailed report/plan 2021/2022

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FOREWORD

Sailing through troubled waters

Mário Pimenta
President

We are navigating, since many years, through troubled waters. Storm after storm has surged: after the financial and the economic crisis, the COVID-19 crisis and now the war in Europe.

Also during these years we lost several LIP founders, José Mariano Gago already in 2015, Gaspar Barreira in 2019, and Armando Policarpo in April 2021. Armando Policarpo was decisive in the creation, consolidation and development of LIP by bringing in, at the very beginning, his high scientific and academic credibility, and throughout the years his clairvoyance and wisdom.

In 2010, the financial/economic crisis hit the Portuguese scientific system in a moment of growth, with many young scientists eager to engage in competitive but sound scientific and academic careers. LIP was not an exception but, for better or worse, we succeeded to keep on track many of our young scientists, although being forced to use in excess the precarious resource of project-funded post-doc positions, as many other institutions had to do.

In 2016/2019, the role of Science, including Fundamental Science, as key factor for Portuguese societal and economic development was again recognized. However, strong financial constrains were still present and, on the other hand, a mid- and long-term agreement between the universities, the scientific institutions, and the government, was not reached. In fact, even among the main scientific institutions, the Associate Laboratories, there wasn't, and there still is not a common vision on how the system should be organized, or on what should be the responsibilities of each peer. The only basic agreement is on the need for increasing the public funding for science, which is clear but not at all enough. Nevertheless, the replacement of the vast majority of the post-doc grants by 5/6-years contracts was a clear improvement. At LIP we have fully used all the possible opportunities to secure scientific employment, and several critical situations were mitigated.

Anyhow, by the end of 2019, some encouraging perspectives were on the horizon, namely:

- The LIP classification as "Excellent" in the evaluation of the Portuguese Research Units.
- The announcement of the opening of the new call for the attribution (renewal) of the status of Associate Laboratory.
- The steady growth of LIP in previous years, by the inclusion of new groups on phenomenology, nuclear physics, social physics and complexity, enlarging and enriching the LIP scientific scope and increasing the potential of collaboration with other Portuguese institutions.
- The positive signs of a consistent economic growth in Portugal.

But then, suddenly, COVID-19 emerged, imposing enormous challenges on the sanitary safety of the population in general and, in particular, forcing the work paradigm to change to remote interchanges whenever possible, since access to the experimental sites became severely constrained. Nevertheless, LIP was able to adapt and re-invent its procedures, trying to help society and being able to keep our scientific production standards, as detailed in the previous and present reports. There was even an increase on the number of MSc and PhD students and on the offer of academic training opportunities, such as the LIP Summer Internship Program, where a record of almost one hundred first-cycle university students were engaged last summer.

Simultaneously, in dialog with the relevant LIP internal bodies, namely the Scientific Council Board and, after its creation, the workers council, new organizational steps have been pursued:

- The first internal evaluation of all members of the Scientific Council who are LIP integrated researchers, and of all LIP staff was done, leading to a well-deserved salary progression of the majority of the LIP administrative and technical employees and a better articulation of some of the technical and administrative LIP services.
- A Grants Office was created to support applications to European projects.
- A new Scientific-Technical Career was created aiming to better frame the work of the physicists and top technical staff engaged in central scientific and service tasks.
- The plans and procedures for the opening of new permanent research positions and for the career evolution of the present permanent researchers were proposed.
- New regulations on the composition of the jury of mid-term research positions were approved.
- New regulations on the organization of the staff training programs were proposed.
- A Code of Conduct to be observed at LIP was proposed.

- An Ethics Committee was created to monitor scientific projects and proposals, whenever needed, and to respond to questions raised in the course of research activities.

These steps aim to better prepare LIP for the challenges of its growth in terms of the number of groups and members, projects and activities, and to potentiate the necessary growth in funding, namely from European sources.

A piece of recent and very good news was the approval of four new European projects submitted by the LIP Distributed Computing and Digital Infrastructures Group.

And now, when COVID-19 started to be hopefully under control, and signs of economic growth were back, the unthinkable war in Europe broke out. Our first word is of a clear and strong condemnation of the Ukraine's brutal invasion by Russia, and of solidarity with the suffering Ukrainian people. LIP will use all possible Portuguese and/or European funding programs to support the temporary integration at LIP of Ukrainian scientists, that were forced to abandon their country. But also of Russian scientists who, not agreeing with the Russian invasion, have to face exile. War is back, and, once again, the future became more uncertain and every scientific institution, including CERN, will have to adapt to the new reality.

On a small note of optimism, let´s really hope that finally we will be able to meet in July in Coimbra, for the 2022 Jornadas do LIP.

March 2022
Mário Pimenta

RESEARCH Areas and Lines

Experimental particle and **astroparticle physics**

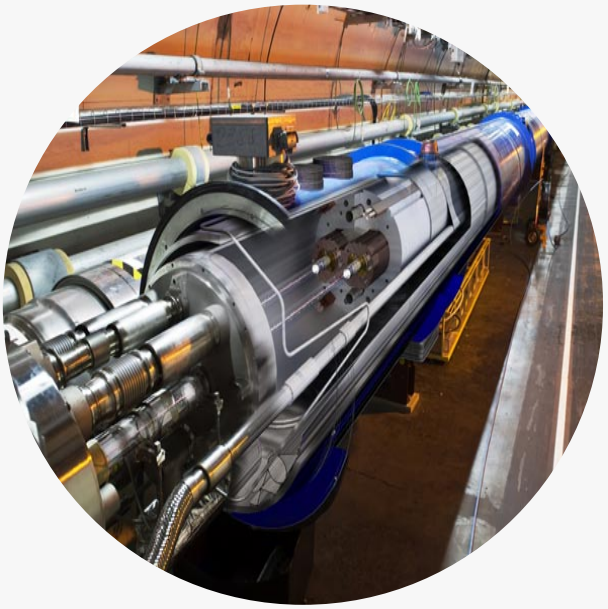
- LHC experiments and phenomenology
- Structure of matter
- Cosmic rays
- Dark matter and neutrinos

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

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

Computing and Information Technologies

Scientific Computing



[LHC experiments and phenomenology]

ATLAS

CMS

Pheno

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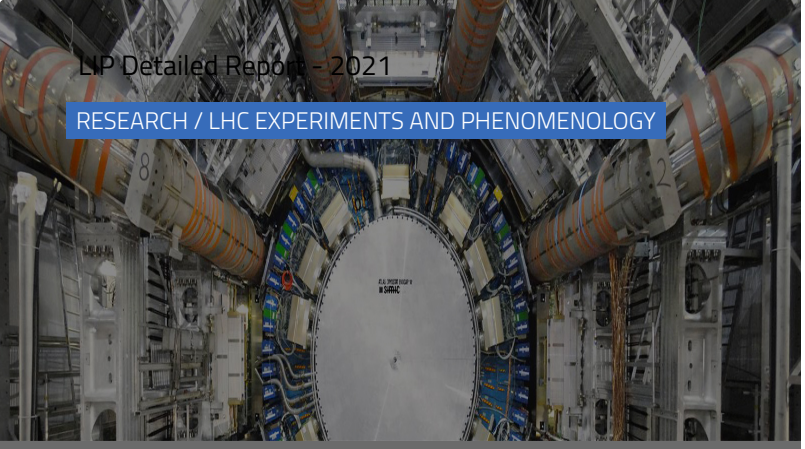

ATLAS

Collaboration in the ATLAS experiment at CERN

Principal Investigator:
Patricia Conde (80)

16 ***Researcher(s):***
Agostinho Gomes (83), Amélia Maio (30), António Onofre (16), António Pina (26), Filipe Veloso (80), Guiomar Evans (30), Helena Santos (76), Helmut Wolters (60), Inês Ochoa (20), João Gentil (70), Marcin Stolarski (30), Miguel Fiolhais (30), Nuno Castro (30), Ricardo Gonçalo (70), Rute Pedro (88), Tiago Vale (72)

6 ***Technician(s):***
Filipe Cuim (100), Filipe Martins (100), Gabriela Pinhão (33), Luís Gurriana (85), Luís Seabra (100), Rui Fernandez (100)

9 ***PhD Student(s):***
Ana Carvalho (100), Ana Peixoto (71), Beatriz Pinheiro Pereira (82), Emanuel Gouveia (46), Luis Coelho (76), Maura Teixeira (66), Nuno Fernandes (100), Ricardo Barrué (100), Rudnei Machado (76)

12 ***Master Student(s):***
Catarina Pereira (100), Daniel Neacsu (30), Helena Macedo (50), José Cordeiro (10), João Pedro Pires (7), João Ribeiro (99), Miguel Alves (77), Patrícia Ferreira (30), Pedro Lagarelhos (58), Pedro Rato (74), Ricardo Faria (50), Rui Fernandes Marques (100)

14 ***Undergraduated Student(s) and Trainee(s):***
Bettina Hanlon, Carolina Costa, Ed Reeves, Inês Alexandre Serra, Inês Gonçalves Dias, Joana Reis, João Lucas Teixeira, João Olho Azul, Leander Reascos, Maha Al-Habsi, Pedro Mendeiros, Pedro Sampaio, Rui Ferreira, Simon Hadfield

2 ***Additional LIP collaborator(s):***
Artur Semião (92), Filipe Costa (42)

8 ***External collaborator(s):***
André Wemans, José Rufino, José Soares Augusto, Mikael Chala, Nuno Campos, Rui Santos, Samoila Cosmin, Susana Sério

Total FTE:
28.2

Articles in international journals:	**7** Direct contribution **65** Indirect contribution
Notes:	**6** Internal notes **9** Collaboration notes **5** LIP Students notes
International conferences:	**5** Oral presentations **3** Posters **3** Proceedings
National conferences:	**1** Oral presentation
Nat.& Internat. meetings:	**3** Oral presentations
Collaboration meetings:	**125** Oral presentations
Advanced Training Events:	**11** Oral presentations **9** Student presentations
Seminars:	**6** Seminars **7** Outreach seminars
Articles in Outreach Journals:	**1** Article in Outreach Journal
Completed theses:	**3** PhDs **5** MScs

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, the forward detectors and the jet trigger software. Since the beginning of LHC, we have contributed to detector operation, performance studies, and physics analysis. We contributed to the Higgs boson discovery and are now measuring its properties. We are a reference in top quark physics studies and have exploited this expertise to lead several searches for new physics. We have made important contributions to the ATLAS heavy ion physics programme by studying jets as probes of the quark-gluon plasma (QGP).

Currently, we have a strong team that impacts all the activities we are developing. We are fully responsible for the Detector Control System (DCS) of TileCal, coordinating the Calibration Group and contributing to maintenance and operations (M&O), and to data quality monitoring. Concerning the upgrades for the High Luminosity phase (HL-LHC), we have full responsibility for designing and producing the High Voltage (HV) distribution system. We actively contribute to performance studies such as ageing of the optical components and its effects on physics measurements, and 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, cooling and movement systems, and we are fully responsible for the ALFA DCS.

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

We were in addition engaged in the ATLAS Hardware Track Trigger (HTT), with responsibility for the production of a communication board. After careful re-evaluation of the project, the ATLAS Collaboration decided to abandon using dedicated hardware processors for tracking at trigger level. This opened the possibility for us to join the High Granularity Timing Detector (HGTD), for which we were already designing and building the HV patch panels. We are in the process of formally joining the group, with responsibilities in the DCS system and front-end ASIC tests.

As for physics analysis, 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 (vector-like quarks, 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 (EFT) Working Group (LHCeftWG) 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 the development of software tools to facilitate and speed up the publication process within the ATLAS Physics Office Group.
We have a fruitful collaboration with LIP research infrastructures (LOMaC, eCRLab), the SimBigData Competence Center and other groups at LIP, namely the Pheno Group.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Ricardo Gonçalo	Agostinho Gomes	191.250 €	2019-09-01 / 2021-09-30	CERN/FIS-PAR/0033/2019 / ATLAS Upgrade 2019/20
Patricia Conde	Nuno Castro	180.000 €	2019-09-01 / 2021-08-31	CERN/FIS-PAR/0002/2019 / Collaboration in the ATLAS Experiment at CERN: Data Taking and Analysis
Inês Ochoa		115.500 €	2020-07-01 / 2023-06-30	Fundação La Caixa - Inês Ochoa / Bolsa Pós-doc Progama Júnior Leader “la Caixa”
Patricia Conde	Nuno Castro	165.000 €	2021-09-01 / 2023-08-31	CERN/FIS-PAR/0010/2021 / Collaboration in the ATLAS experiment at CERN
Ricardo Gonçalo	Agostinho Gomes	192.672 €	2021-10-01 / 2023-09-30	CERN/FIS-PAR/0026/2021 / C-ATLAS Upgrade 2021/23

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). Our goals are to study the Yukawa coupling of the Higgs boson to the b- and t-quarks (including the spin and CP properties in the coupling vertices). We also develop improved methods to identify boosted H→bb decays. 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 leads 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. Currently, we are studying heavy-flavour jets production.

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 contribute to the Laser calibration and study the radiation hardness of the optics.
- Jet Trigger (R. Gonçalo). Using our wide expertise in jet reconstruction, hadronic calibration and real-time algorithms, we contribute 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 real-time parallel algorithms that use GPUs as hardware accelerators, particularly for the calorimeter cluster reconstruction.
- HGTD (R. Gonçalo). We are joining the ATLAS High Precision Timing Detector, with responsibilities in the DCS system and the production of 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)
- TileCal Institutes Board (A. Maio, A. Gomes)
- Trigger/DAQ Institutes Board (R. Gonçalo)
- Forward Detectors Board (P. Conde, N. Castro)
- TileCal Phase II Upgrade Steering Committee (A. Gomes)
- ATLAS International Computing Board (H. Wolters)
- ATLAS Speakers Committee (N. Castro)

Assessment of the past year: objectives vs. achievements

Physics studies

Precision measurements:

- In the WH analysis last year we focused on the definition of statistically optimal observables in the search for anomalous spin/CP couplings. A preliminary study of Machine Learning (ML) inference-based methods (MadMiner and SALLY) indicated a potential gain of a factor five in the exclusion limits with respect to current ATLAS methods.
- Strong contribution to the ATLAS measurement of ttH associated production with full Run 2 data, submitted for publication in December 2021.
- Leading contribution to the CP-sensitive analysis of ttH production, aiming for publication in the Moriond 2022 conference.

- Finished the deployment of the first version of a new H/X→bb tagging algorithm optimised for the Higgs boson, resulting in an improved background rejection and a public simulation-based note for the BOOST2020 conference.
- Started developing an improved H→bb "continuous tagger" that defines the probability of an event being signal or background (instead of a cut), based on a Neural Network tagger.
- Began collaboration with SLAC to explore graph networks for vertexing algorithms to improve b-tagging and H→bb tagging capabilities at higher energies. Progress in this task was limited due to other higher priority objectives.
- One of the team members (N. Castro) acted as co-convener of the LHCeftWG, being the contact person with the top-quark community and organising the work within this scope. During 2021 efforts on the definitions of proper flavour assumptions for an LHC-wide EFT combination were performed, resulting in a recommendations report under preparation.

Direct searches for new physics phenomena:

- Finished the search for vector-like quarks in the multilepton channels using the full Run 2 data.
- Explored the interpretation of the vector like quark searches in terms of alternative production and decay modes.
- Concluded the search for flavour changing neutral currents in the tZq vertex using the full Run 2 data.
- Led and actively contributed to the search for monotop events using the full Run 2 dataset.
- Developed a topology-based approach to maximise the physics information obtained with the Run 3 search lead and/or participated by LIP.
- Contributed to the combination of heavy resonance searches with responsibility for the VH (V=W,Z) statistical analysis. The publication target date was postponed, but it is now on track for a 2022 publication.
- Leading the 2D resonance search in the Y→XH channel using the full Run 2 data and anomaly detection methods. This search is on track for a publication date in early/mid 2022.
- Continued leading the subgroup dedicated to new physics searches in final states with multiple bosons and/or Higgs bosons, a 2-year appointment that ends in April 2022.

Heavy Ion physics:

- Concluded the analysis on the muon+jet trigger, which became a crucial contribution to the paper on the configuration and performance of b-jet triggers during Run 2 (published).
- Performed the optimisation of the hyperparameter space of the DL1 algorithm for b-tagging in heavy ion collisions.
- Contributed to software developments on the Deep Neural Networks algorithms.

Detector maintenance, operation and upgrade

Forward Detectors:

- ALFA DCS: Finished the ISEG migration to OPC UA in the Lab system and assisted the new motherboards tests for the production system. LS2 Upgrades implemented, including new hardware (DCS machine and Power Distribution Unit), software migrations, moving OPC DA from Windows Virtual machine to OPC UA on Linux for ISEG power supply. Missing PLC server to OPC UA because of failed tests in integrating PLC into WinCC S7 native driver.
- AFP DCS: Finished the production system LS2 Upgrade, implemented a new OPC UA for movement system and general upgrades for the cooling, movement and vacuum systems.
- CEP (Central Exclusive Production) di-jet triggers:
  - Finished the implementation of the algorithms and trigger chain. The validation of the software has also been performed.
  - Prepared the SuperChic MC simulation configuration to produce CEP di-jet events for the trigger validation. The production will soon be done at ATLAS (centrally managed).
  - The performance studies were delayed due to the central ATLAS MC production (still ongoing).

TileCal Operations and Performance

- Constantly updating the operations group about potential problems with the hardware when faults are flagged by DCS or by analysing the data collected by DCS.
- The DCS SCADA system was migrated to a newest version available for production systems.
- The new control software for the legacy HV bulk power supply is still under test due to instability in the monitoring. Further developments made, leading to the implementation of extra data validation, are being tested.
- The improvement of the DCS logging is a continuous process as control scripts are being modified.
- The DCS on-call training documentation was updated, and a training zoom session took place during 2021.
- Maintained regular contribution to the Data Quality activities (four validator and one leader shifts).
- Radiation hardness of scintillators and WLS fibres: started exploring Cesium calibration data at a sub-cell level aiming to increase the precision of the estimates on the HL-LHC phase, and cross-checked the analysis using channel level data. The results will be included in the TileCal Run 2 operations paper.

- Coordination of calibration: started preparing calibration procedures, software and operations for the next LHC Run 3, expected to begin in Spring 2022.
- Wrote and approved the internal notes of laser calibration activities in Run 2 and PMT linearity as support for the laser Run 2 paper.
- Completed the first draft of the laser Run 2 paper. A team member is the main editor of this paper.

TileCal Phase II Upgrade:

- Produced final/almost final prototypes of HVremote and HVbus boards, cables, HV supplies crate and associated boards. Some of these were used in the test beam at CERN.
- Performed a vertical slice test of most of the HV system, which will be followed by Production Readiness Reviews of the HV packages.
- The production of the test benches for the quality control of the HV boards and cables was delayed.
- A SCADA prototype was developed and used, in combination with the HV hardware, during the test beam data taking periods.
- The modified firmware for the new auxiliary boards had been tested and is now in use during test beams.
- Implemented offline software updates needed for simulation and Run 3 offline updates.

Jet Trigger preparations for Run 3:

- Contributed to the readiness and optimisation of the Jet Trigger for the Run 3, by performing detailed studies of new tracking configurations and Jet Vertex Tagger options for single jets and combined triggers.
- Contributed to the global Trigger Menu development and Trigger Menu Expert Shifts during the integration milestone weeks.

Trigger Phase II Upgrade:

- Given the cancellation of the HTT project, recent group activities focused on finishing performance studies towards a final publication that demonstrates the potential gains of such a system:
  - Finished the di-muon trigger performance study using the Z→mumu channel as a benchmark.
  - Studied the use of the Hough Transform as an alternative tracking algorithm for the HTT trigger.
  - Did some tests of the Tracking Processor board intended for HTT.
- GPU-accelerated calorimeter reconstruction:
  - Finished the implementation of the TAC algorithm (TopoAutomatonClustering, the GPU version of the TopoClustering) in the new AthenaMT framework and its validation against the standard TopoCluster.
  - Optimised the TAC algorithm to reduce execution times, reaching a speed-up factor of 3.5 (5.5) for di-jet events (ttbar fully hadronic decays) in comparison with the CPU version. These results represent a significant improvement with respect to the first Trigger GPU prototype.

HGTD:

- The group started contributing to the HGTD detector: designed the HV patch panels and filters; produced and tested a filter prototype, in collaboration with the LIP Detectors Laboratory.

Distributed computing

- Prepared ATLAS Distributed Computing (ADC) operations for the challenges of the upcoming data taking for Run 3:
- Extended the ADC Site Status Board with more monitoring information:
  - Improved tools and organisation of the Computing Run Coordination.
  - Continued updating the Portuguese Tier2 operation to the changes in the ATLAS computing model.

Outreach and advanced training

Despite the pandemic, the group contributed to the online IPPOG Masterclasses in Portugal and hosted 14 summer students as part of the LIP Internship Programme (three of them from Liverpool University).

Lines of work and objectives for next year

Physics studies

Precision measurements:

- Finish the study of the ML inference-based methods to maximise the potential of the searches for anomalous Spin/CP components in the hWW vertex.
- Contribute to the Run 2 Legacy paper on the measurement of the high pT H→bb decays in VH production.
- Publish the CP-sensitive analysis of ttH production.
- Contribute to the ttH(H→bb) Run 2 legacy paper: including the c-tagging calibration, machine learning methods, and increasing the sensitivity of the CP measurement.
- Contribute to development and calibration of new X→bb taggers to be used in both Higgs physics and new physics searches.

- Explore graph networks for vertexing algorithms in collaboration with SLAC to improve b-tagging and H→bb tagging capabilities at higher energies.
- 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:

- Finalise and publish the combination of heavy resonance searches with full Run 2 data.
- Finalise and publish the 2D resonance search in the Y→XH channel using the full Run 2 data, using anomaly detection methods.
- Continue leading the subgroup dedicated to new physics searches in final states with multiple bosons and/or Higgs bosons, a 2-year appointment that ends in April 2022.
- 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 at ATLAS, using fully hadronic topologies.

Heavy Ion physics:

- Continue our contributions to the software of the deep neural network (DNN), mostly in heavy ion collisions.
- Study the performance of the DIPs DNN algorithm 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.
- Lead the study of heavy-flavour jet production at large transverse momentum, benefiting from the b-tagging techniques developed in our group.

Detector maintenance, operation and upgrade

Forward Detectors:

- ALFA DCS: implement a DIM communication protocol between DCS machine and PLC for the vacuum system and general upgrades and documentation.
- AFP DCS: develop a software interlock for the vacuum system in case of a vacuum failure. New secondary panels and 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

- Contribute to the operation of the detector during the period of data taking by:
  - Performing DCS expert on-call shits (one week per shift) and being the backup of the DCS expert on-call shifter (24/7).
  - Continuous upgrade and debugging of the DCS software and corrections to accommodate any issues with hardware.
  - Provide adequate training for the on-call shifters.
- Perform the migration of the SCADA systems (WINCC OA) located at the test benches (laboratories) to the latest version.
- Continue the regular contributions to the Data Quality activities with validator and leader shifts.
- Optics radiation hardness:
  - Finish the Run 2 study, including cesium data at sub-cell level, study and integrate dose rate effects in the degradation model and conclude the internal note reporting the results.
  - Start ageing monitoring with Run 3 data.
  - Initiate simulation of the effects of optics degradation in TileCal performance in the HL-LHC.
- Calibration coordination: prepare for TileCal calibration readiness and supervise the detector calibration.
- Conclude the approval process of the laser Run 2 paper.

TileCal Phase II Upgrade:

- Produce final prototypes of HVremote and HVsupplies boards, in collaboration with LIP's eCRLab.
- Finish the vertical slice test of the complete HV system, followed by Production Readiness Reviews of the HV packages and the first pre-productions (depending on components availability).
- Produce test benches for the quality control of the HV boards and cables.
- Proceed with the development and test of the DCS software for the HV control and monitoring.
- Design and develop the new SCADA software components for the Phase II auxiliary boards, which will use the recently tested firmware.
- Finish the development of the initial SCADA component for the Phase II low voltage system.
- Analyse the Run 2 and Run 3 TileMu data.
- Performance studies of the TileMu trigger at HL-LHC, using the digital readout.

Jet Trigger preparations for Run 3:

- The focus will be on the readiness of the jet trigger for Run 3, with performance studies in simulation and using real data (as soon as it becomes available).
- Contribute to the monitoring/validation shifts to ensure high-quality data.
- Contribute to the global trigger menu development and expert shifts.

Trigger Phase II Upgrade:

- Contribute to a public note documenting the HTT performance studies performed.
- Continue the development of the GPU-accelerated calorimeter reconstruction:
  - Improve the current algorithm by reducing differences with respect to offline reconstruction.
  - Study the performance and limitations when running in multi-threaded mode.
  - Implementation of a realistic GPU-accelerates trigger chain including the TAC algorithm, TopoCluster splitter and ID tracking running on GPUs.

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

- Contribute to the electronics work package: HV patch panels/filters design and production; possibly also with tests of the front-end ASIC.
- Contribute to the DCS work package: design and implementation of part of the HGTD DCS, possibly including firmware production for readout boards.

Distributed computing:

- Maintain the ADC Site Status Board and guarantee its stability.
- Organisation of the Computing Run Coordination.
- Operation of the Portuguese Tier 2 during the data taking.

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

In proton-proton collision physics, the 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. In addition, we aim at enhancing the sensitivity to new physics by improving the reconstruction and analysis techniques of the boosted H to bb decays and new physics searches using advanced ML methods.

Regarding the Heavy Ion physics programme, the main objective of our group for the next few years is to probe the nature of the energy loss of the partons as they traverse the QGP by measuring the modification of heavy-flavour jet (b-jets) production.

The group will continue its commitments in detector maintenance and operation activities in the TileCal, the jet trigger system and the forward detectors. In addition, a strong effort will be dedicated to the detector upgrades. Regarding the TileCal, the main endeavour will be the full production of the new high voltage distribution system for the Phase II Upgrade, involving the Portuguese industry, and the continuous upgrades of the detector control system. Systematic studies of the ageing of the optical components (scintillators and fibres) and its impact on the expected performance of the detector in jet measurements 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 addition, we are joining the High Precision Timing Detector with responsibility in the DCS system and the production of patch panels for the HV distribution system.

SWOT Analysis

Strengths

The group accumulates know-how in calorimetry, DCS, software triggers and physics analyses. We count on laboratories in Lisbon (LOMaC) dedicated to calorimetry instrumentation; preparation, quality control and characterisation of optical fibres, plastic scintillators and photodectors. There is also expertise in electronics and advanced computing. We have a fruitful collaboration with the electronics eCRLab and the Detectors Lab at LIP.

Our long expertise in top quark physics has driven us to lead many studies of top quark properties and searches for new physics phenomena. We have expertise in Higgs and Heavy Ion 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 post-Docs 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 at some of the nodes continues to be small. 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.

As already demonstrated in the last few years, the Portugal-CERN PhD grants program, together with the challenges of the LHC Upgrade and the physics opportunities of Runs 2 and 3, continue to provide excellent opportunities for funding high-level students in all areas, including technical research topics.

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

Threats

The human power situation of the group continues to be delicate, particularly in what corresponds to 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.

ATLAS

Publications

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

- *"Finding new physics without learning about it: anomaly detection as a tool for searches at colliders"*, M. Crispim Romao, N. F. Castro, R. Pedro, EPJC 81 (2021) 27
- *"Light Higgs searches in t(t)over-bar phi production at the LHC"*, Duarte Azevedo, Rodrigo Capucha, Emanuel Gouveia, Antonio Onofre, Rui Santos, J. High Energy Phys. 4 (2021) 77
- *"Measurement of the associated production of a Higgs boson decaying into b-quarks with a vector boson at high transverse momentum in pp collisions at \sqrt(s)=13TeV with the ATLAS detector"*, ATLAS Collaboration (2927 authors), Phys. Lett. B 816 (2021) 136204
- *"A continuous integration and web framework in support of the ATLAS Publication Process"*, Juan Pedro Araque Espinosa, Gabriel Baldi Levcovitz, Riccardo-Maria Bianchi, Ian Brock, Tancredi Carli, Nuno Filipe Castro, Alessandra Ciocio, Maurizio Colautti, Ana Carolina Da Silva Menezes, Gabriel De Oliveira da Fonseca, Leandro Domingues Macedo Alves, Andreas Hoecker, Bruno Lange Ramos, Gabriela Lemos Lúcidi Pinhão, Carmen Maidantchik, Fairouz Malek, Robert McPherson, Gianluca Picco, Marcelo Teixeira Dos Santos, JINST 16 (2021) T05006
- *"Anomalous jet identification via sequence modeling"*, A. Kahn, J. Gonski, I. Ochoa, D. Williams and G. Brooijmans, JINST, 16(08):P08012, 2021
- *"Configuration and performance of the ATLAS b-jet triggers in Run 2"*, ATLAS Collaboration, Eur. Phys. J. C 81 (2021) 1087
- *"The LHC Olympics 2020 a community challenge for anomaly detection in high energy physics"*, G. Kasieczka et al, ROPP Vol 84, No. 12, p124201

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

- *"Measurements of top-quark pair single- and double-differential cross-sections in the all-hadronic channel in pp collisions at root s=13 TeV using the ATLAS detector"*, ATLAS Collaboration (2926 authors), J. High Energy Phys. 1 (2021) 033
- *"A search for the dimuon decay of the Standard Model Higgs boson with the ATLAS detector"*, ATLAS Collaboration (2926 authors), Phys. Lett. B 812 (2021) 135980
- *"Measurement of the jet mass in high transverse momentum Z(-> b(b)over-bar)gamma production at root s=13 TeV using the ATLAS detector"*, ATLAS Collaboration (2926 authors), Phys. Lett. B 812 (2021) 135991
- *"Search for phenomena beyond the Standard Model in events with large b-jet multiplicity using the ATLAS detector at the LHC"*, ATLAS Collaboration (2926 authors), Eur. Phys. J. C 81 (2021) 11
- *"Higgs boson production cross-section measurements vand their EFT interpretation in the 4l decay channel at root s =13 TeV with the ATLAS detector (vol 80, 10.1140/epjc/s10052-020-8227-9, 2020)"*, ATLAS Collaboration (2897 authors), Eur. Phys. J. C 81 (2021) 29
- *"Search for the HH -> b(b)over-barb(b)over-bar process via vector-boson fusion production using proton-proton collisions at root s = 13 TeV with the ATLAS detector (vol 7, 108, 2020)"*, ATLAS Collaboration (2926 authors), J. High Energy Phys. 1 (2021) 145
- *"Differential cross-section measurements for the electroweak production of dijets in association with a Z boson in proton-proton collisions at ATLAS"*, ATLAS Collaboration (2927 authors), Eur. Phys. J. C 81 (2021) 163
- *"Search for squarks and gluinos in final states with jets and missing transverse momentum using 139 fb(-1) of root s=13 TeV pp collision data with the ATLAS detector"*, ATLAS Collaboration (2927 authors), J. High Energy Phys. 2 (2021) 143
- *"Medium-Induced Modification of Z-Tagged Charged Particle Yields in Pb plus Pb Collisions at 5.02 TeV with the ATLAS Detector"*, ATLAS Collaboration (2945 authors), Phys. Rev. Lett. 126 (2021) 072301
- *"Measurements of WH and ZH production in the H -> bb decay channel in pp collisions at 13Te with the ATLAS detector"* , ATLAS Collaboration (2927 authors), Eur. Phys. J. C 81 (2021) 178
- *"Search for dark matter in association with an energetic photon in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2926 authors), J. High Energy Phys. 2 (2021) 226
- *"Search for phenomena beyond the Standard Model in events with large b-jet multiplicity using the ATLAS detector at the LHC (vol 81, 11, 2021)"*, ATLAS Collaboration (2926 authors), Eur. Phys. J. C 81 (2021) 249
- *"Search for type-III seesaw heavy leptons in dilepton final states in pp collisions at root s=13TeV with the ATLAS detector"*, ATLAS Collaboration (2928 authors), Eur. Phys. J. C 81 (2021) 218
- *"Longitudinal Flow Decorrelations in Xe plus Xe Collisions at root s(NN)=5.44 TeV with the ATLAS Detector"*, ATLAS Collaboration (2917 authors), Phys. Rev. Lett. 126 (2021) 122301
- *"Measurement of light-by-light scattering and search for axion-like particles with 2.2 nb(-1) of Pb+Pb data with the ATLAS detector"*, ATLAS Collaboration (2933 authors), J. High Energy Phys. 3 (2021) 243
- *"Search for Higgs boson production in association with a high-energy photon via vector-boson fusion with decay into bottom quark pairs at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2928 authors), J. High Energy Phys. 3 (2021) 268
- *"Search for pair production of scalar leptoquarks decaying into first- or second-generation leptons and top quarks in proton-proton collisions at s =13 TeV with the ATLAS detector"*, ATLAS Collaboration (3259 authors), Eur. Phys. J. C 81 (2021) 313
- *"Search for heavy resonances decaying into a pair of Z bosons in the l(+)l(-)l '(+)l '(-) and l(+)l(-)nu(nu)over-bar final states using 139 fb(-1) of proton-proton collisions at root s=13TeV with the ATLAS detector"*, ATLAS Collaboration (2926 authors), Eur. Phys. J. C 81 (2021) 332
- *"Optimisation of large-radius jet reconstruction for the ATLAS detector in 13 TeV proton-proton collisions"*, ATLAS Collaboration (2928 authors), Eur. Phys. J. C 81 (2021) 334
- *"Search for new non-resonant phenomena in high-mass dilepton final states with the ATLAS detector (vol 11, 005, 2020)"*, ATLAS Collaboration (2926 authors), J. High Energy Phys. 4 (2021) 142
- *"Search for new phenomena in events with two opposite-charge leptons, jets and missing transverse momentum in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2928 authors), J. High Energy Phys. 4 (2021) 165

- *"Search for new phenomena with top quark pairs in final states with one lepton, jets, and missing transverse momentum in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2927 authors), J. High Energy Phys. 4 (2021) 174
- *"Higgs boson production cross-section measurements vand their EFT interpretation in the 4l decay channel at root s = 13 TeV with the ATLAS detector (vol 80, 957, 2020)"*, ATLAS Collaboration (2941 authors), Eur. Phys. J. C 81 (2021) 398
- *"Observation of photon-induced W+ W- production in pp collisions at root s=13 TeV using the ATLAS detector"*, ATLAS Collaboration (2928 authors), Phys. Lett. B 816 (2021) 136190
- *"Search for new phenomena in final states with b-jets and missing transverse momentum in root s=13 TeV pp collisions with the ATLAS detector"*, ATLAS Collaboration (2810 authors), J. High Energy Phys. 5 (2021) 093
- *"Search for the HH -> b(b)over-barb(b)over-bar process via vector-boson fusion production using proton-proton collisions at root s = 13 TeV with the ATLAS detector (vol 7, 108, 2020)"*, ATLAS Collaboration (2952 authors), J. High Energy Phys. 5 (2021) 207
- *"Study of energy response and resolution of the ATLAS Tile Calorimeter to hadrons of energies from 16 to 30 GeV"*, Jalal Abdallah et al. (72 authors), Eur. Phys. J. C 81 (2021) 549
- *"Measurements of Higgs bosons decaying to bottom quarks from vvector boson fusion production with the ATLAS experiment at root s=13 TeV"*, ATLAS Collaboration (2835 authors), Eur. Phys. J. C 81 (2021) 537
- *"Measurements of W+W-+ >= 1 jet production cross-sections in pp collisions at s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2887 authors), J. High Energy Phys. 6 (2021) 3
- *"Search for trilepton resonances from chargino and neutralino pair production in root s=13 TeV pp collisions with the ATLAS detector"*, ATLAS Collaboration (2937 authors), Phys. Rev. D 103 (2021) 112003
- *"Search for new phenomena in events with an energetic jet and missing transverse momentum in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2907 authors), Phys. Rev. D 103 (2021) 112006
- *"Search for doubly and singly charged Higgs bosons decaying into vector bosons in multi-lepton final states with the ATLAS detector using proton-proton collisions at root s=13 TeV"*, ATLAS Collaboration (2928 authors), J. High Energy Phys. 6 (2021) 146
- *"Search for charged Higgs bosons decaying into a top quark and a bottom quark at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2923 authors), J. High Energy Phys. 6 (2021) 145
- *"Search for pair production of third-generation scalar leptoquarks decaying into a top quark and a tau-lepton in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2922 authors), J. High Energy Phys. 6 (2021) 179
- *"Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at s=13 TeV"*, ATLAS Collaboration (2935 authors), Eur. Phys. J. C 81 (2021) 578
- *"Test of the universality of tau and mu lepton couplings in W-boson decays with the ATLAS detector"*, ATLAS Collaboration (2937 authors), Nat. Phys. 17 (2021) 813-+
- *"Search for charged-lepton-flavour violation in Z-boson decays with the ATLAS detector"*, ATLAS Collaboration (2937 authors), Nat. Phys. 17 (2021) 819-+
- *"Performance of the ATLAS RPC detector and Level-1 muon barrel trigger at root s=13 TeV"*, ATLAS Collaboration (2842 authors), J. Instrum. 16 (2021) P07029
- *"Search for squarks and gluinos in final states with one isolated lepton, jets, and missing transverse momentum at root s=13 with the ATLAS detector"*, ATLAS Collaborationatlas (2936 authors), Eur. Phys. J. C 81 (2021) 600
- *"Measurements of differential cross-sections in four-lepton events in 13 TeV proton-proton collisions with the ATLAS detector"*, ATLAS Collaboration (2919 authors), J. High Energy Phys. 7 (2021) 005
- *"Two-particle azimuthal correlations in photonuclear ultraperipheral Pb plus Pb collisions at 5.02 TeV with ATLAS"*, ATLAS Collaboration (2833 authors), Phys. Rev. C 104 (2021) 014903
- *"Search for supersymmetry in events with four or more charged leptons in 139 fb(-1) of root s=13 TeV pp collisions with the ATLAS detector"*, ATLAS Collaboration (2932 authors), J. High Energy Phys. 7 (2021) 167
- *"A search for the decays of stopped long-lived particles at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2865 authors), J. High Energy Phys. 7 (2021) 173
- *"Measurement of the relative B-c(+/-)/B-+/- production cross section with the ATLAS detector at root s=8 TeV"*, ATLAS Collaboration (2912 authors), Phys. Rev. D 104 (2021) 012010
- *"Search for Displaced Leptons in root s=13 TeV pp Collisions with the ATLAS Detector"*, ATLAS Collaboration (2836 authors), Phys. Rev. Lett. 127 (2021) 051802
- *"Determination of the parton distribution functions of the proton from ATLAS measurements of differential W-+/- and Z boson production in association with jets"*, ATLAS collaboration (2825 authors), J. High Energy Phys. 7 (2021) 223
- *"Jet energy scale and resolution measured in proton-proton collisions at s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2944 authors), Eur. Phys. J. C 81 (2021) 689
- *"Measurements of the inclusive and differential production cross sections of a top-quark-antiquark pair in association with a Z boson at root s=13 TeV with the ATLAS detector"*, Atlas Collaboration (2939 authors), Eur. Phys. J. C 81 (2021) 737
- *"Measurements of sensor radiation damage in the ATLAS inner detector using leakage currents"*, ATLAS Collaboration (2859 authors), J. Instrum. 16 (2021) P08025
- *"Measurement of single top-quark production in association with a W boson in the single-lepton channel at root s=8 TeV with the ATLAS detector"*, ATLAS Collaboration (2936 authors), Eur. Phys. J. C 81 (2021) 720
- *"Evidence for Higgs boson decays to a low-mass dilepton system and a photon in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2879 authors), Phys. Lett. B 819 (2021) 136412
- *"Exclusive dimuon production in ultraperipheral Pb plus Pb collisions at root S-NN=5.02 TeV with ATLAS"*, ATLAS Collaboration (2953 authors), Phys. Rev. C 104 (2021) 024906
- *"Search for bottom-squark pair production in pp collision events at root s=13 TeV with hadronically decaying tau-leptons, b-jets, and missing transverse momentum using the ATLAS detector"*, G. Aad et al. (2929 authors), Phys. Rev. D 104 (2021) 032014

- *"Search for dark matter produced in association with a single top quark in root s=13 TeV pp collisions with the ATLAS detector"*, ATLAS Collaboration (2935 authors), Eur. Phys. J. C 81 (2021) 860
- *"Search for New Phenomena in Final States with Two Leptons and One or No b-Tagged Jets at root S=13 TeV Using the ATLAS Detector"*, ATLAS Collaboration (2870 authors), Phys. Rev. Lett. 127 (2021) 141801
- *"Search for squarks and gluinos in final states with one ivsolated lepton, jets, and missing transverse momentum at root s = 13 TeV with the ATLAS detector (vol 81, 600, 2021)"*, ATLAS Collaboration (2939 authors), Eur. Phys. J. C 81 (2021) 956
- *"Search for R-parity-violating supersymmetry in a final state containing leptons and many jets with the ATLAS experiment using root s=13 TeV proton-proton collision data"*, ATLAS Collaboration (2872 authors), Eur. Phys. J. C 81 (2021) 1023
- *"Measurement of light-by-light scattering and search for axion-like particles with 2.2 nb(-1) of Pb+Pb data with the ATLAS detector (vol 2021, 243, 2021)"*, ATLAS Collaboration (2923 authors), J. High Energy Phys. 11 (2021) 050
- *"Search for resonances decaying into photon pairs in 139 fb(-1) of pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2922 authors), Phys. Lett. B 822 (2021) 136651
- *"Measurement of the t(t)over-bart(t)over-bar production cross section in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2869 authors), J. High Energy Phys. 11 (2021) 118
- *"Measurement of the production cross section of pairs of isolated photons in pp collisions at 13 TeV with the ATLAS detector"*, ATLAS Collaboration (2887 authors), J. High Energy Phys. 11 (2021) 169
- *"Search for dark matter produced in association with a Standard Model Higgs boson decaying into b-quarks using the full Run 2 dataset from the ATLAS detector"*, ATLAS Collaboration (2865 authors), J. High Energy Phys. 11 (2021) 209
- *"Search for exotic decays of the Higgs boson into long-lived particles in pp collisions at root s=13 TeV using displaced vertices in the ATLAS inner detector"*, ATLAS Collaboration (2870 authors), J. High Energy Phys. 11 (2021) 229
- *"Measurement of b-quark fragmentation properties in jets using the decay B-+/- -> J/psi K-+/- in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2814 authors), J. High Energy Phys. 12 (2021) 131

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

- *"Measurement of hadronic event shapes in high-p(T) multijet final states at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2927 authors), J. High Energy Phys. 1 (2021) 188
- *"Search for a heavy Higgs boson decaying into a Z boson and another heavy Higgs boson in the llbb and llWW final states in pp collisions at sqrt(s) = 13 TeV with the ATLAS detector"*, ATLAS Collaboration (2928 authors), Eur. Phys. J. C 81 (2021) 396

3 International Conference Proceedings

- *"The ATLAS Hardware Track Trigger performance studies for the HL-LHC"*, A. L. Moreira de Carvalho on behalf of the ATLAS Collaboration, PoS(LHCP2020)247
- *"Getting the public closer to the experimental facilities: How Virtual Reality helps High Energy Physics experiments engage public interest"*, Ana Peixoto et al., PoS ICHEP2020 (2021) 954
- *"New results on the modification of jet structure in Heavy Ion collisions"*, Helena Santos, on behalf of the ATLAS, ALICE and CMS Collaborations, PoS(LHCP2021) 082

6 Internal notes

- *R. Pedro, B. Pereira et al: "ATLAS Tile Calorimeter calibration with the Laser system during LHC Run 2", accepted for publication in ATL-TILECAL-INT-2021-007*
- *H. Santos: "b-jet triggers in Pb+Pb collisions", ATL-COM-PHYS-2019-607*
- *Helena Santos et al. ATLAS Collaboration: "Measurement of flow and transverse momentum correlations in Pb+Pb collisions at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV and Xe+Xe collisions at $\sqrt{s_\mathrm{NN}} = 5.44$ TeV with the ATLAS detector", ATL-COM-PHYS-2020-693*
- *ATLAS Tile Caloriemeter: "The replacement of Crack and MBTS Scintillator Detector Modules for Phase-I Upgrade of the Tile Calorimeter", ATL-TILECAL-INT-2021-003*
- *R. Barrué, P. Conde Muíño, R. Pedro, et. al: "Measurement of the associated production of a Higgs boson decaying to bb quarks with a vector boson at high transverse momentum in s√=13s=13 TeV pppp collisions with the ATLAS detector,", ATL-COM-PHYS-2020-017*
- *Helena Santos et al. (ATLAS Collaboration): "Measurement of two-particle correlations in pp collisions at 13 TeV with an active rejection of Jets", ATL-COM-PHYS-2020-164*

9 Collaboration notes with internal referee

- *"Measurement of flow and transverse momentum correlations in Pb+Pb collisions at 5.02 TeV and Xe+Xe collisions at 5.44 TeV with the ATLAS detector"*, ATLAS Collaboration (Helena Santos et al.), ATLAS-CONF-2021-001
- *"Measurement of the sensitivity of two particle correlations in pp collisions at 13TeV to presence of jets with the ATLAS detector"*, ATLAS Collaboration (Helena Santos et al.), ATLAS-CONF-2020-018
- *"Summary of ATLAS diboson searches"*, ATLAS Collaboration (I. Ochoa et. al.), ATL-PHYS-PUB-2021-018
- *"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"*, ATLAS Collaboration (N. Castro et. al.), ATLAS-CONF-2021-024
- *"Identification of Boosted Higgs Bosons Decaying Into bb¯ With Neural Networks and Variable Radius Subjets in ATLAS"*, ATLAS Collaboration (I. Ochoa et al.), ATL-PHYS-PUB-2020-019,
- *"Efficiency corrections for a tagger for boosted H→bb¯ decays in pp collisions at √s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (I. Ochoa et al.), ATL-PHYS-PUB-2021-035
- *"Top Quarks + X Summary Plots September 2021"*, ATLAS Collaboration (F. Veloso et. al.), ATL-PHYS-PUB-2021-037
- *"Search for flavor-changing neutral-current couplings between the top quark and the Z boson with LHC Run2 proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$ with the ATLAS detector"*, ATLAS Collaboration (F. Veloso et. al.), ATLAS-CONF-2021-049

- *"Top Quarks + X Summary Plots December 2021"*, ATLAS Collaboration (F. Veloso et. al.), ATL-PHYS-PUB-2021-041

5 LIP Students Notes

- *"Study on H→bb¯ tagger Robustness against Changes in QCD Background Generation"*, Augustin Vestner, I. Ochoa, CERN-STUDENTS-Note-2021-109
- *"Experimental Particle Physics with the ATLAS detector"*, Helena Lessa and Inês Serra, LIP-STUDENTS-21-26
- *"Anomaly detection as a test of new physics phenomena in CERN ATLAS experiment data"*, Edward Reeves, Rui Ferreira, Nuno Castro, Rute Pedro, LIP-STUDENTS-21-31
- *"Deep Neural Network applications in experimental physics analysis"*, Pedro Mendeiros, Helena Santos, LIP-STUDENTS-21-33
- *"Machine Learning methods to measure the quantum numbers of the Higgs interaction to W bosons"*, J. Teixeira, R. Barrué, I. Ochoa, P. Conde Muíño, LIP-STUDENTS-21-36

1 Article(s) in Outreach Journal(s)

- *"Bringing new life to ATLAS data"*, I. Ochoa, S. Demers, ATLAS Briefins

Presentations

5 Oral presentations in international conferences

- Ana Luísa Carvalho: *"Studies of the CP properties of the Higgs boson at the ATLAS experiment"*, 2021-05-25, Phenomenology Symposium, University of Pittsburgh (remote)
- Helena Santos, on behalf of the ATLAS Collaborations: *"New results on the modification of jet structure in Heavy Ion collisions"*, 2021-06-07, LHCP2021 - Large Hadron Collider Physics, Online
- Nuno Castro: *" EFT studies in the top quark sector (and beyond)"*, 2021-09-02, Energy Frontier Workshop - Restart [Snowmass], online
- R. Pedro: *"Deep Learning for the Classification of Quenched Jets"*, 2021-09-05, PANIC 2021, Lisbon online

3 Poster presentations in international conferences

- Helena Santos, on behalf of the ATLAS Collaborations: *"Collective dynamics of heavy ion collisions in ATLAS"*, 2021-07-12, ISMD2021 - International symposium on multiparticle dynamics, Online
- Helena Santos, on behalf of the ATLAS Collaboration: *"Collective dynamics of heavy ion collisions in ATLAS"*, 2021-07-12, 50th International Symposium on Multiparticle Dynamics , Online
- F. Martins, F. Cuim, G. Evans, R. Fernandez, A. Gomes, L. Gurriana, J.A. Soares Augusto,: *"Control System of Upgraded High Voltage for Atlas Tile Calorimeter "*, 2021-10-19, ICALEPCS 2021,

3 Oral presentations in national or international meetings

- Inês Ochoa: *"ATLAS Status Report"*, 2021-06-02, 146th LHCC Meeting - Open Session, CERN, online.
- Ana Luísa Carvalho: *"C-tagging for ttH(bb) legacy analysis"*, 2021-11-08, HTop workshop livepage, online
- Ana Luísa Carvalho: *"Release 22: objects and analysis updates"*, 2021-11-11, HTop workshop, CERN

1 Presentation(s) in national conference(s)

- Ricardo Gonçalo: *"The European Frontier of Particle Physics"*, 2021-06-29, Encontro Ciência 2021,

11 Oral presentations in advanced training events

- António Onofre: *"Top Physics"*, 2021-04-06, LIP Summer Students Lectures,
- Ricardo Gonçalo: *"Higgs Physics 1"*, 2021-04-07, Course on Physics at the LHC,
- Rute Pedro: *"Higgs Physics 3"*, 2021-04-14, Course on Physics at the LHC,
- Agostinho Gomes: *"Particle detectors"*, 2021-07-05, LIP Summer Students Lectures,
- A. Lindote, A. L. Carvalho, R. Sarmento: *"Introduction to C++"*, 2021-07-05, LIP Summer Students Lectures,
- G. Pereira, R. Barrué: *"ROOT Tutorial"*, 2021-07-05, LIP Summer Students Lectures,
- Ana Peixoto: *"Higgs and beyond the Standard Model searches at the LHC"*, 2021-07-05, Course on Physics at the LHC,
- R. Pedro: *"Tutorial LHC Open Data"*, 2021-07-08, LIP Internship 2021, Online
- R. Pedro: *"GNN application to the Higgs ML Kaggle Dataset"*, 2021-07-12, 1st Workshop of Big Data at LIP, Online
- Nuno Castro: *"Probing the Standard Model and Beyond at the LHC"*, 2021-07-15, 6th Lisbon mini-school on Particle and Astroparticle Physics, online
- Ricardo Gonçalo: *"Closing Talk: the European Strategy for Particle Physics"*, 2021-11-20, Advanced CERN Portuguese Teachers School, Online

9 Student presentations in advanced training events

- Ana Carvalho: *" Trigger development for the ATLAS Forward Proton Detector (AFP)"*, 2021-09-06, 10th IDPASC Students Workshop,
- Ricardo Barrué: *"Optimization of the search for CP violation in the Higgs-WW interaction"*, 2021-09-06, 10th IDPASC Students Workshop,
- Maura Teixeira: *"Searching for Dark Matter with the ATLAS Detector using Unconventional Signatures"*, 2021-09-07, 10th IDPASC Students Workshop,
- J. Teixeira, R. Barrue, P. Conde: *"Machine Learning Methods to measure the quantum numbers of the Higgs interaction to W bosons"*, 2021-09-14, LIP Summer Students Final Workshop,
- M. Al-Habsi, I. Ochoa, P. Conde: *"Boosted Higgs boson reconstruction in WH associated production"*, 2021-09-14, LIP Summer Students Final Workshop,
- Ed Reeves, R. Ferreira, R. Pedro, N. Castro: *"Detecção de anomalias como teste de novos fenómenos de física nos dados da*

experiência ATLAS do CERN", 2021-09-14, LIP Summer Students Final Workshop,

- I. Dias, B. Pereira, A. Gomes, J. Gentil, R. Pedro: *"Development of a portable system for scintillation detection"*, 2021-09-14, LIP Summer Students Final Workshop,
- J. Olho Azul, G. Evans, A. Gomes, L. Gurriana: *"Sistema de alta tensão do Tilecal"*, 2021-09-14, LIP Summer Students Final Workshop,
- P. Mendeiros, H. Santos: *"Deep Neural Networks applications in experimental physics data analysis"*, 2021-09-14, LIP Summer Students Final Workshop,

6 Seminars

- Inês Ochoa: *"ATLAS results in fully-hadronic diboson final states"*, 2021-03-18, Particle Phenomenology Seminar, Institute for Theoretical Physics, Heidelberg University, 2021, Heidelberg
- R. Pedro: *"Machine Learning at Colliders"*, 2021-03-24, Universidade de Coimbra - Café com Física,
- Nuno Castro: *"Search for vector-like quarks at the LHC"*, 2021-04-22, CFTP Seminar, online
- Ricardo Gonçalo: *"Collider-Based Experiments "*, 2021-06-09, , FCTUC
- Rute Pedro: *"Tile Calorimeter: Past, Present and Bridges to Future"*, 2021-06-24, LIP Seminar,
- R. Pedro: *"Tile Calorimeter: Past"*, 2021-06-24, LIP Seminar,

7 Outreach seminars

- Inês Ochoa: *"De que são feitas as coisas?"*, 2021-03-24, Colégio Ramalhão, Lisboa
- R. Pedro: *"ATLAS Open Data"*, 2021-04-19, IST Course on Particle Physics Techniques,
- Ricardo Gonçalo: *" Como ver particulas invisiveis"*, 2021-05-17, , E.S. Jaime Cortesao (remote)
- Patricia Conde: *"Física de Partículas: ¿de qué estamos hechos?"*, 2021-07-04, , Colegio Santo Domingo de A Coruña, Spain.
- Ricardo Gonçalo: *"A fronteira Europeia da Fisica de Particulas"*, 2021-09-24, European Researchers Night, Online
- Patricia Conde: *"Physics at CERN"*, 2021-10-02, Give me more Quantum (2021 Congress of the Portuguese Physics Students Association), Online
- Ricardo Gonçalo: *"O Vazio e o Bosão de Higgs"*, 2021-10-28, ESERO 2021,

Theses

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- Emanuel Gouveia: *"Probing the CP nature of the Higgs couplings to top quarks at the Run 2 of the LHC"*, 2016-11-21 / 2021-07-22, (finished)
- Ana Peixoto: *"Search for new interactions in the top quark sector"*, 2016-09-13 / 2021-09-13, (finished)
- Tiago Vale: *"Search for heavy fermions with LHC data"*, 2016-09-13 / 2021-10-24, (finished)
- Susana Santos: *"Study of the ttH production and Higgs couplings to Top quarks in the ATLAS experiment"*, 2010-10-30 , (ongoing)
- Ana Carvalho: *"Study of the CP properties of the Higgs coupling to top quarks with ATLAS at the LHC."*, 2019-01-01 , (ongoing)
- Ricardo Barrué: *"Study of the Spin/CP properties of the Higgs coupling to W-bosons with ATLAS at the LHC"*, 2020-09-01 , (ongoing)
- Maura Teixeira: *"Searching for dark matter with the ATLAS detector using unconventional signatures"*, 2021-01-01 , (ongoing)
- Luis Coelho: *" Exploring the electroweak vacuum with di-Higgs production at the LHC ATLAS experiment"*, 2021-05-01 , (ongoing)
- Beatriz Pinheiro Pereira: *"Radiation Damage of Optical Components in Scintillator Detectors: from the ATLAS/LHC Tile Calorimeter to Future Experiments"*, 2021-02-01 , (ongoing)
- Rudnei Machado: *"Radiation Damage of the TileCal Optics components at the High Luminosity LHC phase"*, 2021-09-01 , (ongoing)

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- Beatriz Pinheiro Pereira: *" Radiation damage of the optical components of the ATLAS TileCal calorimeter at the High-Luminosity LHC"*, 2020-02-01 / 2021-01-18, (finished)
- Pedro Rato: *"Test system for the remote high voltage distribution system of the tilecal "*, 2018-09-01 / 2021-09-14, (finished)
- Nuno Fernandes: *"Development of GPU-Accelerated Trigger Algorithms for the ATLAS Experiment at the LHC"*, 2020-11-17 / 2021-11-16, (finished)
- João Ribeiro: *"Fast tracking co-processor for the ATLAS experiment upgrade for the High Luminosity phase of the LHC"*, 2016-09-01 / 2021-11-17, (finished)
- Ricardo Faria: *"Prospects for the HL-LHC of the measurement of the top quark couplings in the ttbar dileptonic channel"*, 2018-09-16 / 2021-11-29, (finished)
- João Pedro Pires: *"Deep Neural Netwoers in Experimental Data Analyses"*, 2021-11-08 / 2022-12-31, (ongoing)
- Pedro Lagarelhos: *"Prospects for the HL-LHC of the measurement of the top quark couplings in the ttbar semileptonic channel"*, 2018-09-16 , (ongoing)
- Miguel Alves: *"Development of GPU-based Calorimeter Clustering algorithms for the ATLAS Upgrade"*, 2019-09-01 , (ongoing)
- José Cordeiro: *"Development of an FPGA-accelerated clustering for the ATLAS trigger system"*, 2020-02-18 , (ongoing)
- Catarina Pereira: *"Performance of the TileCal High Voltage Upgrade System"*, 2019-09-16 , (ongoing)
- Rui Fernandes Marques: *"Functional tests and calibration of the Tilecal HV prototypes"*, 2016-09-12 , (ongoing)
- Patrícia Ferreira: *"Machine Learning for Anomaly Detection in the Atlas Trigger at the LHC"*, 2021-09-10 , (ongoing)
- Helena Macedo: *"Searching for new heavy resonances with Higgs and vector bosons at the highest energies with the ATLAS detector"*, 2021-09-06 , (ongoing)
- Daniel Neacsu: *"Dark matter searches at the LHC in models with extended scalar sectors"*, 2021-02-01 , (ongoing)

CMS

Collaboration in the CMS experiment at CERN

Principal Investigator:
Michele Gallinaro (100)

8 ***Researcher(s):***
Alessio Boletti (100), Jonathan Hollar (100), João Seixas (30), João Varela (100), Nuno Leonardo (75), Pietro Faccioli (25), Ricardo Bugalho (50), Tahereh Niknejad (100)

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

3 ***PhD Student(s):***
Diogo de Bastos (95), Mariana Araújo (50), Matteo Pisano (100)

2 ***Master Student(s):***
Henrique Legoinha (50), Maria Faria (100)

12 ***Undergraduated Student(s) and Trainee(s):***
Amélia Pinto, Ana Benquerença, Cláudio Pedrosa, Cristina Meng, Hilberto Silva, Madalena Nunes, Manuel Peixoto, Marta Botas, Reza Jafari, Rodrigo Campello Silva, Ruben Pozzi, Timothée Hessel

9 ***External collaborator(s):***
Beatriz Ribeiro Lopes, Carlos Leong, Giles Strong, Luis Ferramacho, Matteo Magherini, Miguel Silveira, Oleksii Toldaiev, Pedrame Bargassa, Pedro Ferreira da Silva

Total FTE:
12.3

Articles in international journals:	**5** Direct contribution **55** Indirect contribution
Preprints:	**2**
Notes:	**14** Internal notes **2** Collaboration notes **4** LIP Students notes
Proposals:	**1** Proposal(s) and related studies
International conferences:	**10** Oral presentations **3** Proceedings
Nat.& Internat. meetings:	**1** Oral presentation **1** Poster
Collaboration meetings:	**69** Oral presentations
Advanced Training Events:	**18** Oral presentations **3** Student presentations
Seminars:	**3** Seminars **4** Outreach seminars
Completed theses:	**1** MSc

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: discovery and characterization of a Higgs boson; measurements of the top quark properties; 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. A group member served as Deputy Spokesperson of the Collaboration in 2012-13.

The group contributed to the Phase-1 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 is currently undergoing maintenance and upgrades in preparation for Run 3, expected to start in 2022. During the long-shutdown (LS2), the group has been involved in the preparation of the PPS and the ECAL detectors.

The LIP group is leading the development of the new forward Precision Proton Spectrometer (PPS) that took physics data integrated in CMS in 2016-18. 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 2027, the accelerator will provide an additional integrated luminosity of 3000 fb^{-1} over 10 years of operation. The LIP group participates in the construction of a new Timing Detector and in the upgrade of the barrel and endcap Calorimeters. The LIP 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 includes also the complete replacement of the endcap calorimeters with a new high-granularity sampling calorimeter. LIP collaborates with industry to supply 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 recent (July 2019) institutional Evaluation Report performed by an international review panel under the initiative of FCT, LIP received the highest quality grade (Excellent). The contribution of the CMS group to this evaluation was explicitly recognized. Quoting the report "The CMS group, while small in size, is really outstanding and world-class".

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
João Varela	Michele Gallinaro	200.000 €	2019-08-01 / 2021-09-15	CERN/FIS-INS/0032/2019 / Collaboration in the Phase 2 Upgrade of the CMS experiment at CERN
Michele Gallinaro	Nuno Leonardo	200.000 €	2019-08-01 / 2021-10-31	CERN/FIS-PAR/0025/2019 / Collaboration in the operation and physics data analysis at the CMS experiment at CERN
João Varela	Michele Gallinaro	200.000 €	2021-09-16 / 2023-09-15	CERN/FIS-INS/0029/2021 / Collaboration in the Phase 2 Upgrade of the CMS experiment at CERN
Jonathan Hollar	Michele Gallinaro	248.366 €	2022-01-01 / 2024-12-31	PTDC/FIS-PAR/1214/2021 / Precision Timing with forward protons at the HL-LHC
Michele Gallinaro	Nuno Leonardo	185.000 €	2021-11-01 / 2023-10-31	CERN/FIS-PAR/0005/2021 / Collaboration in the operation and physics data analysis at the CMS experiment at CERN

CMS

Overview

The goals 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 physics 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 complementary projects:

- The project “Collaboration in the operation and physics data analysis at the CMS experiment at CERN”. The PI is M.Gallinaro. The Co-PI is N.Leonardo.
- The project “Collaboration in the Phase 2 Upgrade of the CMS experiment at CERN”. The PI is Joao Varela. He has 40 years of research experience at CERN. The Co-PI is M.Gallinaro.
- The project “Precision timing with forward protons at the HL-LHC”. The PI is J.Hollar. The Co-PI is M.Gallinaro.

Senior researchers of the LIP/CMS group are: P.Faccioli, M.Gallinaro, J.Hollar, N.Leonardo, J.Seixas, J.Varela.

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

- Group coordinator - M.Gallinaro.
- Deputy group coordinators - N.Leonardo, J.Hollar.
- PI operation and physics data analysis – M.Gallinaro.
- Co-PI operation and physics data analysis – N.Leonardo.
- PI phase 2 upgrade - J.Varela.
- Co-PI phase 2 upgrade - M.Gallinaro.
- Physics Analysis Coordinators - P.Bargassa, P.Faccioli, M.Gallinaro, J.Hollar, N.Leonardo, J.Seixas.
- Detector coordinators: PPS (J.Hollar), ECAL (J.C.Silva).
- Computing link person - D.Bastos.

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

- PPS Deputy Coordinator (Level-1), since 2018 (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, since 2020 (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 Finance 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 (ARC) and Detector Review Committees. Group members convene the following weekly meetings of the CMS Collaboration: PPS general meeting, BTL (Barrel Timing Layer) electronics meeting, B-Physics ERD meeting.

Assessment of the past year: objectives vs. achievements

Despite the difficult situation, there were no major deviations from the goals set for 2021. Within the CMS experimental program, the LIP/CMS group made major scientific contributions in 2021 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 marks ("distinction and honour", Oct. 2020). Lepton Flavor Universality (LFU) studies in the same final state are continuing in collaboration with colleagues at IIT Madras (student A.Kumar). In a similar final state, a study of vector boson scattering (VBS) processes including a tau lepton using the full Run 2 data is pursued in collaboration with colleagues at Univ. of Perugia (students M.Magherini, A.Piccinelli, and T.Tedeschi, M.Gallinaro).

b) Search for SUSY:

Group members (D.Bastos, C.Cruz e Silva, P.Bargassa) previously 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 is in the final phase before the approval process by the collaboration.

c) Search for double Higgs production:

Di-Higgs 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 activity (G.Strong, M.Gallinaro), was the subject of the PhD thesis of G.Strong who graduated with the highest mark in Dec. 2020. The analysis is in the final phase of the approval process by the collaboration. Projections of the expected sensitivity developed for the Yellow Report were updated for different HL-LHC conditions.

d) Search for Dark Matter (DM):

Members of the LIP/CMS group (M.Gallinaro) pursued a search for Dark Matter produced in association with a Higgs boson. The Higgs boson decaying to a final state with four leptons is sought for in events with large missing transverse energy, possibly associated with the DM particles escaping the detector. The search is developed with the full Run 2 data in collaboration with colleagues from Bari.

e) Flavour anomalies and heavy flavour

The study of rare decays remains a priority. The interest is reinforced by the large accumulated 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. Results are under internal review. Alessio Boletti serves as the analysis contact. Maria Faria developed and successfully defended her Master thesis at IST. Involvement of undergraduate students (M.André, R.Jafari, R.Pozzi) contributed to extensions of the work, e.g. exploring the CMS "parked" data.

f) Quarkonia polarization:

The group (M.Araújo, 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.

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

Previously, 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 boson pairs (J.Hollar) and top quark pairs (M.Pisano, M.Gallinaro, J.Hollar) using PPS data.

2) Heavy-ion physics

B mesons as novel probes of QGP:

The group is bringing its unique expertise on B physics into the heavy ion realm and has been playing a leading role in the investigation of first B meson signals in PbPb data. The observation of B meson signals in heavy ion collisions, achieved for the first time by CMS, provides novel probes of the QGP. This work is pursued in collaboration with MIT. The measurement of B_s and B^+ production in PbPb data was accomplished. A group member (N.Leonardo) wrote the observation paper (arXiv:2109.01908). The analyses have been extended to the reference pp dataset (M.Faria and H.Legoinha, N.Leonardo). Henrique Legoinha is starting his Master thesis on the subject.

3) Experiment operation and maintenance

a) Physics objects development:

LIP members pursued their participation in the activities of the Physics Object Groups (POGs), in the validation of forward proton alignment and reconstruction efficiency (M.Pisano), and PPS high-level trigger (M.Araújo). Tag and probe tools for muon measurements with CMS open data were contributed.

b) PPS commissioning and operation:

Under the leadership of a LIP member serving as PPS Project Manager (J.Varela), PPS collected over 100 fb^{-1} of data in Run 2. 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 2018, a LIP member serves as Deputy 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 maintained the ECAL trigger and DAQ system.

d) Computing: A member of the group served as LIP/CMS interface with the LIP's Tier 2 group.

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

4) Phase 2 Upgrades (HL-LHC)

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

a) R&D in 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 full responsibility).

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). The LIP group is responsible for the design and construction of the BTL readout system. One member of the group is presently responsible for coordinating the development of the BTL Readout System.

Dedicated ASIC electronics is used to readout the SiPM arrays. The readout solution uses the new TOFHIR2 chip developed in the framework of the agreement KN436/EP between LIP and CERN. The microelectronics design of the TOFHIR2 circuits is sub-contracted to the Portuguese company PETsys. A first version of the chip (TOFHIR1) was implemented in the same technology as TOFPET2 (UMC CMOS 110nm). The final version (TOFHIR2) is being developed in TSMC CMOS 130 nm technology, which has increased radiation tolerance. The first full version of the chip (TOFHIR2A) was submitted for fabrication in February 2020, and a second version (TOFHIR2X) was submitted in January 2021. Detailed tests started in July 2021 and first results where presented at IEEE in September. In parallel, the TOFHIR2 Test Board (T2TB) was developed as well as an adapter for integration with the available standalone DAQ system. Radiation resistance tests were performed in October 2020 and July 2021 at the x-ray irradiation facility at CERN. Radiation tests at the heavy-ion beam in Louvain were performed in September 2020. A test of the TOFHIR2A coupled to sensor modules in high intensity proton beam was performed in March 2021 at PSI, Switzerland. The results were presented at several conferences and project reviews at CERN.

The front-end (FE) system has three types of boards, the FE Board with the TOFHIR chips interfacing to LYSO/SiPM modules, the Concentrator Card with optical links to the backend, and the Power Conversion Card, which are organized in Readout Units. LIP has the responsibility for the design, production and testing of the FE Boards. Measurements with SiPM sensors and laser beams with two complete Readout Units showed excellent results. The measurements of time resolution with TOFHIR2X and BTL sensor modules match well the expectations. The full detector module (including crystals, test boards, ASICs, and power supplies) was tested at the CERN test beam in October 2021. The final version of the ASIC (TOFHIR2B) was submitted in November 2021.

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

In the context of the full replacement of the electronics of the ECAL, LIP already 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 65nm chip that implements additional digital logic and data transmission (LiTE-DTU chip).

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

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.

A study was performed to identify the HGCAL shower-shape variables which are the most discriminating between VBF processes and Pile-Up (PU) events at the HL-LHC. Results were presented at the HGCAL trigger group. The variables can be included at the L1 trigger as an MVA discriminant and help reduce the high PU rate while preserving the efficiency of VBF events which are of particular interest for the future physics searches at the HL-LHC.

5) Outreach & advanced training

Group members take part in outreach activities for high school and university students (IPPOG Masterclasses, CERN visits, InsideViews, student sessions at LIP room at IST). One 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 2022 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:

- Higgs physics:
  - Search for di-Higgs events in resonant or non-resonant modes in di-tau and bbar final states.
  - 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.
- Electroweak physics:
  - Measurement of the quartic gauge coupling γγWW using the PPS spectrometer.
  - Search for exclusive processes by tagging a leading forward proton using PPS.
- B physics:
  - Exploration of rare decays and flavour anomalies.
- New physics in top like events:
  - Studies of lepton flavor universality in top quark events, and vector boson scattering processes with tau leptons in the final state.
- SUSY physics:
  - Search for SUSY top squark in four-body decays.
- Quarkonia:
  - Precise measurements of the polarizations of the J/psi and other quarkonium states.
- Heavy-ion physics:
  - Explore heavy flavor signals as QGP probes with LHC ion and reference pp datasets.

Task 2: R&D Phase-II Upgrade

- R&D in the Barrel Timing Layer (BTL): Development of the BTL ASIC TOFHiR2 in radiation tolerant CMOS 130 nm technology of TSMC (TOFHIR2). Submission of the final version (TOFHIR2B) and preparation for the wafer production and BGA encapsulation for the detector.
- R&D in the ECAL front-end readout system: Submission and 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). A revised version of the ADC IP including new calibration functionality will be supplied by the Portuguese industry.
- 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.
- 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

- ECAL: Maintenance of the ECAL trigger and data acquisition system.
- PPS: Operation and maintenance of the new pixel and timing detectors and DAQ system of the PPS project.
- 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).
- Computing: LIP/CMS interface with the LIP's Tier2 group.
- General: The LIP group will provide central shifts and EPR (Experimental Physics Responsibilities) work according to the rules of the CMS collaboration.

Medium-term (3-5 years) prospects

In the period 2022-26 the LIP/CMS group plans to keep the participation in the CMS experiment at the same high level of quality, responsibility and visibility.

Physics

We plan to purse the physics analyses of the 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 SM to the precise measurements of the SM properties.

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

The group is responsible for the upgrade of the data acquisition system of the PPS in view of the Run 3 data-taking, and will contribute to the maintenance and operation of the PPS and 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 MIP Timing Detector (MTD), ECAL, and HGCAL in

collaboration with the Portuguese industry, and taking the leadership in the development of the MTD readout system.

- Precision Proton Spectrometer (PPS): With the LHC Run 2 dataset, all measurements using PPS are limited by statistics. Therefore, the detectors will be upgraded and continue to operate in Run 3 to exploit the high luminosity that will be delivered by the LHC.
- Electromagnetic Calorimeter: In the CMS operations in the period 2022-2025, 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 2027. In order 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 MTD (addition of a timing layer in front of the calorimeters for precise timing measurement of all charged particles), in the ECAL (full replacement of the ECAL barrel electronics), HGCAL (complete replacement of the endcap calorimeters with a new high-granularity sampling calorimeter) and PPS detector (R&D on new timing detectors). The 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 CMS 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 high-energy physics.

Opportunities

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

Threats

Unclear career prospects for several senior physicists of the group.

CMS

Publications

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

- *"Timing performance of a multi-pad PICOSEC-Micromegas detector prototype"*, M. Gallinaro et al., Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 993 (2021) 165076
- *"Modeling the timing characteristics of the PICOSEC Micromegas detector"*, J. Bortfeldt et al. (41 authors), Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 993 (2021) 165049
- *"Measurement of the CP-violating phase phi(s) in the B-s(0) -> J/psi phi(1020) -> mu(+)mu-K+K- channel in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), Phys. Lett. B 816 (2021) 136188
- *"Test beam characterization of sensor prototypes for the CMS Barrel MIP Timing Detector"*, CMS MTD Collaboration (199 authors), J. Instrum. 16 (2021) P07023
- *"Advances in Multi-Variate Analysis Methods for New Physics Searches at the Large Hadron Collider"*, M. Gallinaro, G. Strong, J. Varela, et al., Rev.Phys. 7 (2021) 100063

2 Preprints

- *"Vector Boson Scattering Processes: Status and Prospects"*, M. Gallinaro et al., arXiv:2106.01393
- *"Observation of B0s mesons and measurement of the B0s/B+ yield ratio in PbPb collisions at 5.02 TeV"*, CMS Collaboration, arXiv:2109.01908

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

- *"Search for top squark pair production using dilepton final states in pp collision data collected at root s=13TeV"*, CMS Collaboration (2307 authors), Eur. Phys. J. C 81 (2021) 3
- *"Evidence for electroweak production of four charged leptons and two jets in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), Phys. Lett. B 812 (2021) 135992
- *"Measurements of production cross sections of polarized same-sign W boson pairs in association with two jets in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), Phys. Lett. B 812 (2021) 136018
- *"Search for dark matter produced in association with a leptonically decaying Z boson in proton-proton collisions at root s=13TeV"*, CMS Collaboration (2307 authors), Eur. Phys. J. C 81 (2021) 13
- *"Correlations of azimuthal anisotropy Fourier harmonics with subevent cumulants in pPb collisions at root s(NN)=8.16 TeV"*, CMS Collaboration (2299 authors), Phys. Rev. C 103 (2021) 014902
- *"Evidence for Higgs boson decay to a pair of muons"*, CMS Collaboration (2307 authors), J. High Energy Phys. 1 (2021) 148
- *"Search for the lepton flavor violating decay tau -> 3 mu in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2333 authors), J. High Energy Phys. 1 (2021) 163
- *"Studies of charm and beauty hadron long-range correlations in pp and pPb collisions at LHC energies"*, CMS Collaboration (2308 authors), Phys. Lett. B 813 (2021) 136036
- *"Measurements of pp -> ZZ production cross sections and constraints on anomalous triple gauge couplings at root s=13 TeV"*, CMS Collaboration (2327 authors), Eur. Phys. J. C 81 (2021) 200
- *"Search for dark photons in Higgs boson production via vector boson fusion in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 3 (2021) 011
- *"Measurement of the inclusive and differential Higgs boson production cross sections in the leptonic WW decay mode at p root s=13 TeV"*, CMS Collaboration (2321 authors), J. High Energy Phys. 3 (2021) 3
- *"Search for new physics in top quark production with additional leptons in proton-proton collisions at root s=13 TeV using effective field theory"*, CMS Collaboration (2310 authors), J. High Energy Phys. 3 (2021) 095
- *"Measurement of differential t(t)over-bar production cross sections using top quarks at large transverse momenta in pp collisions at root s=13 TeV"*, CMS Collaboration (2379 authors), Phys. Rev. D 103 (2021) 052008
- *"Search for nonresonant Higgs boson pair production in final states with two bottom quarks and two photons in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2310 authors), J. High Energy Phys. 3 (2021) 257
- *"Search for dark matter produced in association with avleptonically decaying Z boson in proton-proton collisions at root s = 13 TeV (vol 81, 13, 2021)"*, CMS Collaboration (2307 authors), Eur. Phys. J. C 81 (2021) 333
- *"Development and validation of HERWIG 7 tunes from CMS underlying-event measurements"*, CMS Collaboration (2370 authors), Eur. Phys. J. C 81 (2021) 312
- *"Measurement of differential cross sections for Z bosons produced in association with charm jets in pp collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 4 (2021) 109
- *"Angular analysis of the decay B+-> K*(892)(+)mu(+)mu(-) in proton-proton collisions at root s=8 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 4 (2021) 124
- *"Search for supersymmetry in final states with two oppositely charged same-flavor leptons and missing transverse momentum in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 4 (2021) 123
- *"Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC"*, CMS Collaboration (2333 authors), J. Instrum. 16 (2021) P05014
- *"Measurement of single-diffractive dijet production in proton-proton collisions at root s = 8 TeV with the CMS and TOTEM experiments (vol 80, 1164, 2020)"*, CMS TOTEM Collaborations / CMS TOTEM Collaborations / TOTEM Collaboration (2366 authors), Eur. Phys. J. C 81 (2021) 383
- *"Measurement of b jet shapes in proton-proton collisions at root s=5.02 TeV"*, A. M. Sirunyan et al. (2296 authors), J. High Energy Phys. 5 (2021) 54
- *"Measurement of prompt D-0 and D-0 meson azimuthal anisotropy and search for strong electric fields in PbPb collisions at root S-NN=5.02 TeV"*, CMS Collaboration (2308 authors), Phys. Lett. B 816 (2021) 136253
- *"In-medium modification of dijets in PbPb collisions at root s(NN)=5.02 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 5 (2021) 116

- *"Study of Drell-Yan dimuon production in proton-lead collisions at root s(NN)=8.16 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 5 (2021) 182
- *"Measurements of the differential cross sections of the production of Z plus jets and gamma plus jets and of Z boson emission collinear with a jet in pp collisions at root s=13 TeV"*, CMS Collaboration (2339 authors), J. High Energy Phys. 5 (2021) 285
- *"Measurements of production cross sections of the Higgs boson in the four-lepton final state in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), Eur. Phys. J. C 81 (2021) 488
- *"Observation of a New Excited Beauty Strange Baryon Decaying to Xi(-)(b)pi(+)pi(-)"*, CMS Collaboration (2359 authors), Phys. Rev. Lett. 126 (2021) 252003
- *"Measurement of the W gamma Production Cross Section in Proton-Proton Collisions at root s=13 TeV and Constraints on Effective Field Theory Coefficients"*, CMS Collaboration (2319 authors), Phys. Rev. Lett. 126 (2021) 252002
- *"Measurements of Higgs boson production cross sections and couplings in the diphoton decay channel at root s=13 TeV"*, CMS Collaboration (2306 authors), J. High Energy Phys. 7 (2021) 027
- *"Search for charged Higgs bosons produced in vector boson fusion processes and decaying into vector boson pairs in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2330 authors), Eur. Phys. J. C 81 (2021) 723
- *"Search for a heavy vector resonance decaying to a Z boson and a Higgs boson in proton-proton collisions at s=13 Te"*, CMS Collaboration (2327 authors), Eur. Phys. J. C 81 (2021) 688
- *"Measurement of the azimuthal anisotropy of Y(1S) and Y(2S) mesons in PbPb collisions at root s(NN)=5.02 TeV"*, CMS Collaboration (2272 authors), Phys. Lett. B 819 (2021) 136385
- *"Search for singly and pair-produced leptoquarks coupling to third-generation fermions in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2353 authors), Phys. Lett. B 819 (2021) 136446
- *"Search for the rare decay of the W boson into a pion and a photon in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2339 authors), Phys. Lett. B 819 (2021) 136409
- *"Search for top squarks in final states with two top quarks and several light-flavor jets in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2323 authors), Phys. Rev. D 104 (2021) 032006
- *"Search for lepton-flavor violating decays of the Higgs boson in the mu tau and e tau final states in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2340 authors), Phys. Rev. D 104 (2021) 032013
- *"Constraints on the Initial State of Pb-Pb Collisions via Measurements of Z-Boson Yields and Azimuthal Anisotropy at root s(NN)=5.02 TeV"*, CMS Collaboration (2363 authors), Phys. Rev. Lett. 127 (2021) 102002
- *"Precision luminosity measurement in proton-proton collisions at root S=13 TeV in 2015 and 2016 at CMS"*, CMS Collaboration (2309 authors), Eur. Phys. J. C 81 (2021) 800
- *"Measurements of angular distance and momentum ratio distributions in three-jet and Z plus two-jet final states in pp collisions"*, CMS Collaboration (2322 authors), Eur. Phys. J. C 81 (2021) 852
- *"Search for top squark production in fully hadronic final states in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2322 authors), Phys. Rev. D 104 (2021) 052001
- *"Search for W ' bosons decaying to a top and a bottom quark at root s=13 TeV in the hadronic final state"*, CMS Collaboration (2298 authors), Phys. Lett. B 820 (2021) 136535
- *"First measurement of the cross section for top quark pair production with additional charm jets using dileptonic final states in pp collisions at root s=13 TeV"*, CMS Collaboration (2325 authors), Phys. Lett. B 820 (2021) 136565
- *"Measurements of the pp -> W-+/-gamma gamma and pp -> Z gamma gamma cross sections at root s=13 TeV and limits on anomalous quartic gauge couplings"*, CMS Collaboration (2306 authors), J. High Energy Phys. 10 (2021) 174
- *"Study of Z boson plus jets events using variables sensitive to double-parton scattering in pp collisions at 13 TeV"*, CMS Collaboration (2312 authors), J. High Energy Phys. 10 (2021) 176
- *"Combined searches for the production of supersymmetric top quark partners in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2333 authors), Eur. Phys. J. C 81 (2021) 970
- *"Measurement of differential t(t)over-bar production cross sections in the full kinematic range using lepton plus jets events from proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2360 authors), Phys. Rev. D 104 (2021) 092013
- *"Measurements of the Electroweak Diboson Production Cross Sections in Proton-Proton Collisions at root s=5.02 TeV Using Leptonic Decays"*, CMS Collaboration (2361 authors), Phys. Rev. Lett. 127 (2021) 191801
- *"Search for a heavy Higgs boson decaying into two lighter Higgs bosons in the tau tau bb final state at 13TeV"*, CMS Collaboration (2335 authors), J. High Energy Phys. 11 (2021) 057
- *"Observation of tW production in the single-lepton channel in pp collisions at root s=13 TeV"*, CMS Collaboration (2337 authors), J. High Energy Phys. 11 (2021) 111
- *"Search for new particles in events with energetic jets and large missing transverse momentum in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2326 authors), J. High Energy Phys. 11 (2021) 153
- *"Probing effective field theory operators in the associated production of top quarks with a Z boson in multilepton final states at root s=13 TeV"*, CMS Collaboration (2323 authors), J. High Energy Phys. 12 (2021) 083
- *"Search for a heavy resonance decaying to a top quark and a W boson at root s=13 TeV in the fully hadronic final state"*, CMS Collaboration (2295 authors), J. High Energy Phys. 12 (2021) 106
- *"Measurement of the top quark mass using events with a single reconstructed top quark in pp collisions at root s=13 TeV"*, CMS Collaboration (2339 authors), J. High Energy Phys. 12 (2021) 161
- *"Measurement of the inclusive and differential t(t)over-bar gamma cross sections in the single-lepton channel and EFT interpretation at root s=13 TeV"*, CMS Collaboration (2329 authors), J. High Energy Phys. 12 (2021) 180
- *"The very forward CASTOR calorimeter of the CMS experiment"*, CMS Collaboration (2430 authors), arXiv:2011.01185

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

- *"Measurement of the Z boson differential production cross section using its invisible decay mode (Z -> nu(nu)over-bar) in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 5 (2021) 205
- *"Observation of B0→ψ(2S)K0Sπ+π− and B0s→ψ(2S)K0S decays"*, CMS Collaboration, CMS-PAS-BPH-18-004
- *"Search for resonant and nonresonant new phenomena in high-mass dilepton final states at root s=13 TeV"*, CMS Collaboration (2324 authors), J. High Energy Phys. 7 (2021) 208
- *"Search for long-lived particles using displaced jets in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2351 authors), Phys. Rev. D 104 (2021) 012015
- *"Hard color-singlet exchange in dijet events in proton-proton collisions at root s=13 TeV"*, CMS Collaboration / TOTEM Collaboration (2419 authors), Phys. Rev. D 104 (2021) 032009
- *"Search for chargino-neutralino production in events with Higgs and W bosons using 137 fb(-1) of proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2359 authors), J. High Energy Phys. 10 (2021) 045
- *"Study of dijet events with large rapidity separation in proton-proton collisions at sqrt(s) = 2.76 TeV"*, CMS Collaboration, arXiv:2111.04605
- *"A precision measurement of the W boson decay branching fractions in proton-proton collisions at 13 TeV"*, CMS Collaboration, arXiv:2201.07861
- *"Measurement of prompt open-charm production cross sections in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2336 authors), J. High Energy Phys. 11 (2021) 225
- *"Identification of hadronic tau lepton decays with a deep neural network"*, CMS Collaboration, arXiv:2201.08458
- *"Search for Higgs boson decays into Z and J/ψ and for Higgs and Z boson decays into J/ψ or Y pairs at CMS"*, CMS Collaboration, CMS-PAS-HIG-20-008
- *"Measurement of the inclusive and differential ttgamma cross section and EFT interpretation in the dilepton channel at 13 TeV"*, CMS Collaboration, arXiv:2201.07301
- *"Measurement of the production cross section for Z+b jets in proton-proton collisions at 13 TeV"*, CMS Collaboration, arXiv:2112.09659

3 International Conference Proceedings

- *"Search for new physics in b→sℓ+ℓ− transitions at CMS"*, A. Boletti, on behalf of the CMS Collaboration, PoS(ICHEP2020)365
- *"Study of central exclusive production of top quark-antiquark pairs at LHC"*, M. Pisano, Nuovo Cimento 44C (2021) 66
- *"Rare heavy-flavour decays"*, A. Boletti (on behalf of the ATLAS, CMS, and LHCb Collaborations), PoS(LHCP2021)139

1 Proposal(s) and related studies

- *"The CMS Precision Proton Spectrometer at the HL-LHC -- Expression of Interest"*, CMS Collaboration, arXiv:2103.02752

14 Internal Notes

- *"Exploiting Precision Proton Spectrometer forward protons for triggering"*, M. Araujo, J. Hollar, CMS AN-2021/037
- *"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
- *"B meson RAA and Cross Section Ratios in pp and PbPb Collisions at 5.02 TeV"*, N.Leonardo, M.Faria, H. Legoinha, et al , CMS AN-2021/091
- *"Proton reconstruction with the Precision Proton Spectrometer in Run 2"*, J. Hollar et al., CMS AN-2021/084
- *"Data Mixing vs Monte Carlo Mixing on the PPS"*, H. Silva, J. Hollar, CMS AN-2021/113
- *"Search for Higgs boson pairs produced through gluon and vector boson fusion in the bbtautau final state with Run 2 data"*, M. Gallinaro, M. Pisano, G. Strong, et al., CMS AN-2018/121
- *"Search for non-resonant Higgs boson pair production in final states with two bottom quarks and two tau leptons in pp collisions at 13 TeV"*, CMS Collaboration, CMS-PAPER-HIG-20-010
- *"Searching for exclusively produced top quark pairs"*, M. Gallinaro, J. Hollar, P. Silva et al., CMS AN-2018/239
- *"Measurement of the B0 -> K* mu mu decay branching fraction at 13 TeV"*, M. Faria, A. Boletti, N. Leonardo, CMS AN-2021/104
- *"Exclusive WW and ZZ production in the fully hadronic channel with protons reconstructed in PPS"*, J. Hollar et al., CMS AN-2019/211
- *"Full angular analysis of decay B0 -> K* mu mu at 13 TeV"*, A. Boletti et al., CMS AN-2018/138
- *"Combination of the searches for exclusive production of top quark pairs in the dilepton and lepton+jets channels"*, M. Gallinaro, J. Hollar, M. Pisano, P. Silva, et al., CMS AN-2021/038
- *"Vector Boson Scattering of same-sign W boson pairs with a hadronic tau in the final state using the early Run II dataset"*, M. Gallinaro et al., CMS AN-2021/042
- *"Search for central exclusive production of top quark pairs in pp collisions at 13 TeV recorded with the CT-PPS"*, M. Pisano, P. Silva, et al., CMS AN-2020/004

2 Collaboration notes with internal referee

- *"Results with the TOFHIR2X revision of the front-end ASIC of the CMS MTD Barrel Timing Layer"*, T. Niknejad et al., CMS-CR-2021-291
- *"Lepton universality tests and searches for charged lepton violation at CMS"*, M. Gallinaro (on behalf of the CMS collaboration), CMS CR-2021/281

4 LIP Students Notes

- *"Muon efficiency performance with Tag and Probe using CMS Open Data with Z boson decaying into dimuons"*, Rodrigo Campello, LIP-STUDENTS-21-10
- *"Investigating flavor anomalies via $B^0 \rightarrow K^{0*} \mu \mu$ decay using CMS data"*, Marta Botas , Reza Jafari and Ruben Pozzi, LIP-STUDENTS-21-23
- *"Measurement of $B^{\pm}$ meson cross section in pp collisions at the LHC"*, Henrique Legoinha, LIP-STUDENTS-21-22
- *"Search for dark matter in association with a new Z' boson at the LHC in proton-proton collisions at 13 TeV"*, Madalena Nunes and Amélia Pinto, LIP-STUDENTS-21-18

Presentations

10 Oral presentations in international conferences

- M. Gallinaro: *"Time of flight measurements"*, 2021-02-16, Workshop on Gaseous detector contributions to Particle Identification, CERN (online)
- M. Araújo, P. Faccioli, C. Lourenço and T.Thomas Madlener: *"Towards the understanding of quarkonium production through global-fit analyses of LHC data"*, 2021-03-17, QWG 2021, CERN (online)
- T. Niknejad: *"The TOFHIR2 readout ASIC of the CMS MTD Barrel Timing Layer"*, 2021-04-18, APS April Meeting 2021,
- A. Boletti: *"Rare heavy-flavour decays"*, 2021-06-10, LHCP 2021, Paris (online)
- M. Araujo: *"Measurements of quarkonium polarization with CMS"*, 2021-08-06, A Virtual Tribute to Quark Confinement and the Hadron Spectrum 2021, CERN (online)
- M. Gallinaro: *"Lepton universality tests and searches for charged lepton flavor violation with the CMS experiment"*, 2021-09-08, NuFact 2021, 22nd International workshop on neutrinos from accelerators, Cagliari, Italy (online)
- T. Niknejad: *"First experimental results with the version TOFHIR2X of the front-end ASIC of the MTD/BTL detector in the CMS experiment"*, 2021-09-18, TWEPP 2021 Topical Workshop on Electronics for Particle Physics, online
- M. Gallinaro: *"Small-x and diffraction: summary"*, 2021-10-15, 12th International Workshop on Multiple Partonic Interactions at the LHC, Lisbon
- J. Hollar, A. Mehta: *"WG2 (Double Parton Scattering) Summary"*, 2021-10-15, 12th International Workshop on Multiple Partonic Interactions at the LHC , Lisbon
- T. Niknejad: *"Results with the TOFHIR2X version of the front-end ASIC of the CMS Barrel Timing Layer"*, 2021-10-19, IEEE NSS MIC 2021, online

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

- M. Gallinaro: *"Experimental collaboration: LHC and beyond, a personal view"*, 2021-11-26, FCC Engagement meeting, Lisbon (online)

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

- M. Pisano: *"Poster session: My PhD project in high energy physics."*, 2021-11-22, IST PhD Open days, IST

18 Oral presentations in advanced training events

- J. Varela: *"Experimental program at the LHC"*, 2021-03-01, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon (online)
- J. Varela: *"Introduction to collisions at LHC"*, 2021-03-03, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon (online)
- J. Varela: *"Future endeavors in Particle Physics"*, 2021-05-10, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon (online)
- J. Hollar: *"Lecture on the Course on Physics at the LHC 2021: "Standard Model Processes""*, 2021-03-22, Course on Physics at the LHC 2021, Lisbon (online)
- M. Gallinaro: *"Top quark: Introduction"*, 2021-03-24, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon
- M. Gallinaro: *"Top quark: Properties and beyond"*, 2021-03-29, Course on Physics at the LHC 2021, Lisbon
- M. Gallinaro: *"Higgs boson: Beyond the SM searches"*, 2021-04-14, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon
- M. Gallinaro: *"Exotic processes and Dark Matter"*, 2021-04-28, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon (online)
- N. Leonardo: *"Flavour physics"*, 2021-05-03, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon (online)
- N. Leonardo: *"Flavour anomalies and beyond standard model"*, 2021-05-05, IDPASC School 2021: Course on Physics at the LHC 2021, Lisbon (online)
- M. Gallinaro: *"The experimental program at the LHC"*, 2021-06-01, Doctorate Course at University of Perugia (XXXVI ciclo), Perugia, Italy
- M. Gallinaro: *"Probing the Standard Model at the LHC"*, 2021-06-03, Doctorate Course at University of Perugia (XXXVI ciclo), Perugia, Italy

3 Student presentations in advanced training events

- H. Legoinha, M. Faria, N. Leonardo: *"Heavy quarks as probes of the primordial plasma"*, 2021-09-14, LIP Internship Program Final Workshop, Lisbon (online)
- M. Andre, R. Jafari, R. Pozzi, A. Boletti, M. Faria, N. Leonardo: *"Investigating the Flavor Anomalies"*, 2021-09-14, LIP Internship Program Final Workshop, Lisbon (online)
- R. Silva, E. Melo, N. Leonardo, A. Jales, S. Fonseca: *"Muon efficiency for Z bosons with T&P using CMS Open Data"*, 2021-09-14, LIP Internship Program Final Workshop, Lisbon (online)

3 Seminars

- J. Hollar: *"The CMS Precision Proton Spectrometer: Past, Present, and Future"*, 2021-01-21, LIP-Lisbon Seminar, Lisbon (online)
- T. Niknejad: *"Precision Timing with the CMS MTD Barrel Timing Layer for HL-LHC"*, 2021-02-04, LIP-Lisbon Seminar, Lisbon (online)
- N. Leonardo et al.: *"CMS Physics Overview and Strategy "*, 2021-03-25, LHC Line Strategy Discussion, Lisbon (online)

4 Outreach seminars

- M. Pisano, M. Occhetto: *"How to contribute to the professional development of physics high school teachers"*, 2021-02-09, Physics italian PLS ("Piano Lauree Scientifiche"), Catania (online)
- D. Bastos: *"Welcome: Meet LIP-CMS"*, 2021-03-16, Jornadas de Engenharia Física, IST (online)
- N. Leonardo: *"New Physics at the LHC and beyond"*, 2021-05-05, Jornadas de Engenharia Fisica 7, IST
- J. Hollar: *"Introduction to CMS and the LIP CMS group"*, 2021-08-06, LIP CMS Summer Students Meeting, CERN+Lisbon (online)

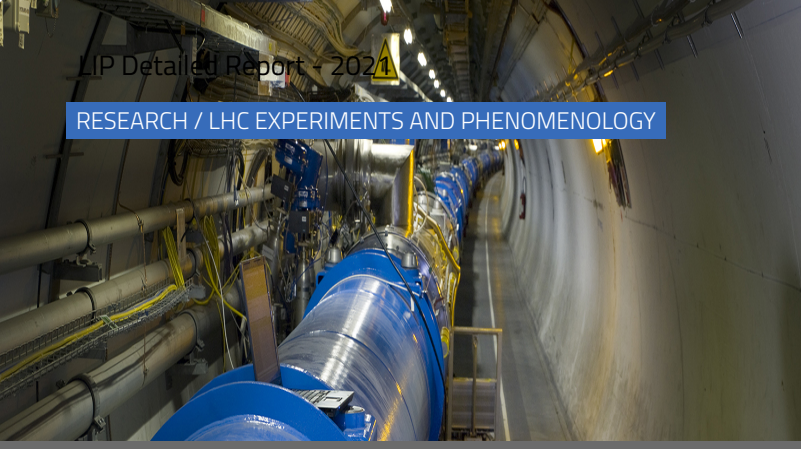
Theses

3 PhD

- Diogo de Bastos: *"Search for the supersymmetric stop quark in the CMS experiment"*, 2017-11-19 , (ongoing)
- Mariana Araújo: *"Quarkonium production studies at LHC energies: towards the understanding of bound-state formation by the strong force"*, 2018-02-12 , (ongoing)
- Matteo Pisano: *"Search for new physics in exclusive processes at the Large Hadron Collider"*, 2020-07-10 , (ongoing)

2 Master

- Maria Faria: *"Investigating the flavour anomalies through the rare beauty decay $B^0 \to K^{0*} \mu\mu$"*, 2020-09-14 / 2021-10-22, (finished)
- Henrique Legoinha: *"Probing the properties of the plasma of quarks and gluons with heavy flavour"* (ongoing)



PHENO

Phenomenology

Principal Investigator:
Guilherme Milhano (100)

16 ***Researcher(s):***
António Onofre (60), Carlota Casas (81), Filipe Veloso (20), Grigorios Chachamis (100), Helmut Wolters (17), João Nuno Pires (100), João Seixas (15), Liliana Apolinário (84), Miguel Fiolhais (60), Miguel Romão (100), Nuno Castro (30), Pablo Rodriguez (23), Pietro Faccioli (50), Ricardo Gonçalo (15), Ruben Conceição (15), Susana Coito (83)

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Henrique Carvalho (21)

8 PhD Student(s):
André Cordeiro (83), Esteban Chalbaud (33), Guilherme Guedes (100), João Martins da Silva (99), João Pedro Gonçalves (82), Maria Ramos (100), Mariana Araújo (50), Susana Santos (100)

5 ***Master Student(s):***
André Reigoto (87), João Humberto Gomes (25), João Lopes (100), Nuno Madureira (75), Pedro Lagarelhos (50)

1 ***Additional LIP collaborator(s):***
Gonçalo Gonçalves (25)

5 ***Undergraduated Student(s) and Trainee(s):***
Alexandre Monforte, André Santos, Daniela Cardoso, Diogo Simões, João Miguel Fernandes

20 ***External collaborator(s):***
Alessandro Broggio, Andrea Ferroglia, André Pereira, Carlos Lourenço, Fernando Souza, Filipa Peres, Francisco del Aguila Giménez, Fábio Dominguez, José Santiago Perez, João Lourenço Barata, Juan Antonio Aguilar Saavedra, Korinna Zapp, Lénea Luís, Mehraveh Nikjoo, Mikael Chala, Orlando Oliveira, Osvaldo Freitas, Paulo J. Silva, Rui Santos, Solange Nunes

Total FTE:
20.3

Articles in international journals:	**11** Direct contribution
Preprints:	**1**
Notes:	**2** LIP Students notes
International conferences:	**8** Oral presentations **3** Proceedings
Nat.& Internat. meetings:	**6** Oral presentations
Advanced Training Events:	**1** Oral presentation
Seminars:	**4** Seminars **1** Outreach seminar
Completed theses:	**1** PhD **2** MScs

Executive summary

LIP's Phenomenology group conducts research bridging theory and experiment in particle and astroparticle physics. While independent, its research is centred around areas in which LIP has active experimental activities and aims to identify areas in which LIP's broader programme may evolve in the future. Its purpose is to strengthen the impact of the overall LIP programme through the provision of excellent directed phenomenological research.

Since its creation in 2018, the group has steadily grown in size and in the breadth of its research programme. It now addresses several topical issues also covered by LIP's experimental groups allowing for synergies to develop. Success examples include studies in New Physics searches and jet quenching studies conducted jointly with the Competence Center on Simulation and Big Data, and quarkonium production measurements by LIP's CMS group and their phenomenological interpretation in our group.

The group members have maintained, despite the many constraints imposed by the on-going pandemic situation, 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.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Guilherme Milhano		188.500 €	2019-06-01 / 2023-11-30	824093 - STRONG-2020 / The strong interaction at the frontier of knowledge:fundamental research and applications
Guilherme Milhano		399.062 €	2019-10-01 / 2024-09-30	835105 - YoctoLHC / Yoctosecond imaging of QCD collectivity using jet observables
António Onofre		45.000 €	2019-11-15 / 2021-11-14	CERN/FIS-PAR/0029/2019 / Estudos fenomenológicos em LHC na fisica de quarks top e bosões de Higgs
Guilherme Milhano	Liliana Apolinário	90.000 €	2020-07-01 / 2022-06-30	CERN/FIS-PAR/0024/2019 / Bridging Theory and Experiment: Collider Phenomenology
Pietro Faccioli		20.000 €	2020-09-01 / 2022-08-31	CERN/FIS-PAR/0010/2019 / Methods for Understanding Strong Interactions with Quarkonia
António Onofre	Miguel Fiolhais	45.000 €	2021-11-15 / 2023-11-14	CERN/FIS-PAR/0037/2021 / TopHiggsPheno - Estudos Fenomenologicos em LHC na Fisica de Quarks Top e Bosões de Higgs
Liliana Apolinário	Carlota Casas	49.464 €	2021-12-01 / 2023-05-31	EXPL/FIS-PAR/0905/2021 / Unveiling the space-time structure of jets
Grigorios Chachamis	João Nuno Pires	49.922 €	2022-01-17 / 2023-07-16	EXPL/FIS-PAR/1195/2021 / The Strong force and multiparticle dynamics at hadron colliders
Guilherme Milhano	Liliana Apolinário	80.000 €	2022-07-01 / 2024-06-30	CERN/FIS-PAR/0032/2021 / THbridgeEXP-II_A ponte entre Teoria e Experiência: Fenomenologia de Colisionadores (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.

The effort to explore physics opportunities in future collider facilities contributed significantly to the proposal for the creation within LIP of a dedicated group to the Future Circular Collider studies.

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.

Assessment of the past year: objectives vs. achievements

The successful synergies with the Simulation and Big Data competence centre will continue as, increasingly, machine and deep learning techniques become ubiquitous in our work. For the future, we will attempt closer collaborations with the cosmic ray experimental groups and the NPstrong group.

Finally, the group intends to continue to follow its sustained growth strategy. This involves, in particular, the continuing need to attract further students and researchers to join the group, building on current expertise.

The main objectives for 2021 were:

- increase output and international visibility of the group.
- increase focus on the consolidated areas of research of the group with an effort to identify complementary expertise within the group for new projects.
- further strengthen synergy with the Simulation and Big Data competence centre.
- establish closer collaboration with the cosmic ray experimental groups and the NPstrong group.
- continue the sustained growth of the group through both improvement of the contractual situation of current members and attraction of further researchers.

During 2021:

- despite the many constraints resulting from the pandemic situation, the group members were able to maintain, and in some cases increase their scientific output.
- the appointment of Liliana Apolinário as Theory co-convener of the LHC Heavy Ions Working group, the strong participation of different members of the group as session convener, discussion leader and speaker in the INT-Seattle programme 'Probing QCD at High Energy and Density with Jets', and the continued leadership of a work package in the STRONG2020 consortium illustrate the high international visibility of the group.
- collaborations within the group have been increased both in what regards the common interest in anomaly detection in QCD and New Physics Studies, and in merging diverse QCD interests into successful funding applications.
- a postdoctoral researcher, working in heavy-ion phenomenology, was hired.
- two MSc students successfully defended their theses and the first PhD thesis entirely conducted within the group will be defended in early 2022.
- the continued impossibility of in-person meetings has delayed progress in establishing synergies with cosmic ray experimental groups and the NPstrong group.
- a member of the group was awarded a 6-year contract in the FCT Scientific Employment call, contributing to the medium-term stability of the group.

The group maintained an excellent publication record across its research programme.

Lines of work and objectives for next year

We will continue to focus on the existing consolidated areas that have proven to be very successful and with a vast international reach into an even more competitive level. This includes the core group portfolio on top physics, Higgs, quarkonia, QCD precision physics, heavy-ions, and BSM physics.

The pursued lines of work will be focus on data-driven/model-independent studies, with a particular aim to harness the full

potential of the next phases of the LHC. In particular, in what regards the need for theoretical precision matching experimental uncertainties from high-luminosity runs and the high potential of collisions of lighter-than-Lead ions to elucidate the mechanisms of emergence of complexity from the simple fundamental laws of QCD. This on-going effort brings together complementary expertise, in heavy-ion phenomenology and precision collider physics, within the group.

The successful synergies with the Simulation and Big Data competence centre will continue as, increasingly, machine and deep learning techniques become ubiquitous in our work both for New Physics Searches and the pioneering understanding of Quark-Gluon Plasma time evolution from jet observables.

Finally, the group intends to continue to follow its sustained growth strategy. This involves, in particular, the continuing need to attract 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 centered around the following lines of action:

1. Promoting a wide-scope high-quality research programme in Phenomenology.
2. Contributing to the shaping of LIP's evolving research programme.
3. Nurtur current intra-LIP synergies while further developing collaborations with LIP areas that share common research interests.
4. Stable structural funding through team members' general and separate funded projects.

To fulfill its role as the phenomenology arm of LIP, the group intends to increase the number of full-time members in the areas of strategic and topical importance to the laboratory. This reinforcement in human resources will help to place the group with a relevant and recognised leading role in data interpretation and innovative analysis dedicated to the next LHC phases.

In the medium term, therefore, the group's identity would be established as a Phenomenology centre of excellence with active collaborations across theory and phenomenology groups nationally and internationally.

SWOT Analysis

Strengths

Internationally recognized research of high impact; strong involvement in the motivation for future high energy physics facilities and new directions within current facilities; demonstrated ability to attract high-quality researchers; growing number of students being trained in the group; funding increasingly distributed across several PIs in the group.

Weaknesses

Insufficient critical mass to cover phenomenologically wealth of physics addressed by experimental groups at LIP; significant part of workforce shared with experimental groups; group geographically spread; inhomogeneous distribution of doctoral students across the research topics of the group.

Opportunities

High level of interest from researchers at various levels of experience to join the group; augmented opportunities to attract doctoral students in the framework of the PT-CERN PhD Grants; ability to increase the coherence of Phenomenology work both at LIP and national level; strong synergy with the Simulation and Big Data Competence Centre at LIP; mature collaborations with centres of excellence including CERN-TH, Santiago de Compostela, Granada, MIT; increasing ability to seek competitive National/European funding.

Threats

Uncertainty in the ability to retain current precariously employed researchers; competition with international centres of excellence offering better medium/long term prospects for hiring new researchers; dependence on funding agency's irregular timeframes for hiring experienced researchers.

Pheno

Publications

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

- *"Constraining the energy spectrum of neutral pions in ultra-high-energy proton-air interactions"*, Lorenzo Cazon, Ruben Conceição, Miguel Alexandre Martins, and Felix Riehn, Phys. Rev. D 103, 022001
- *"Running in the ALPs"*, M. Chala, G. Guedes, M. Ramos and J. Santiago, Eur. Phys. J. C (2021) 81: 181
- *"Use of a Generalized Energy Mover's Distance in the Search for Rare Phenomena at Colliders"*, M. Crispim Romao, N.F. Castro , J.G. Milhano, R. Pedro, T. Vale, Eur. Phys. J. C 81, 192 (2021)
- *"May the four be with you: Novel IR-subtraction methods to tackle NNLO calculations"*, W.J. Torres Bobadilla, G.F.R. Sborlini, P. Banerjee, S. Catani, A.L. Cherchiglia, L. Cieri, P.K. Dhani, F. Driencourt-Mangin, T. Engel, G. Ferrera, C. Gnendiger, R.J. Hernández-Pinto, B. Hiller, G. Pelliccioli, J. Pires, R. Pittau, M. Rocco, G. Rodrigo, M. Sampaio, A. Signer, C. Signorile-Signorile, D. Stöckinger, F. Tramontano, Y. Ulrich, Eur.Phys.J.C 81 (2021) 3, 250
- *"Jet Wake from Linearized Hydrodynamics"*, J. Casalderrey-Solana, J. G. Milhano, D. Pablos, K. Rajagopal and X. Yao, JHEP 05 (2021) 230
- *"Time reclustering for jet quenching studies"*, L. Apolinário, A. Cordeiro, K. Zapp, Eur.Phys.J.C 81 (2021) 6, 561
- *"New leptons with exotic decays: collider limits and dark matter complementarity"*, Guilherme Guedes, José Santiago, arXiv:2107.03429
- *"Multiperipheral final states in crowded twin-jet events at the LHC"*, N. Bethencourt de León, G. Chachamis and A. Sabio Vera, Nucl.Phys.B 971 (2021) 115518
- *"The Large Hadron-Electron Collider at the HL-LHC"*, P. Agostini et al. (337 authors), J. Phys. G-Nucl. Part. Phys. 48 (2021) 110501
- *"Average minijet rapidity ratios in Mueller Navelet jets"*, N. B. de Leon, G. Chachamis and A. Sabio Vera, Eur. Phys. J. C 81, no.11, 1019 (2021)
- *"Deep Learning for the Classification of Quenched Jets"*, L. Apolinário, N. F. Castro, M. Crispim Romão, J. G. Milhano, R. Pedro, F. C. R. Peres, JHEP11 (2021) 219

1 Preprint(s)

- L. A. Anchordoqui, A. Ariga et al *"The Forward Physics Facility: Sites, Experiments, and Physics Potential"*, arXiv:2109.10905 [hep-ph],

3 International Conference Proceedings

- *"Jet substructure modification probes the QGP resolution length"*, J. Casalderrey-Solana, G. Milhano, D. Pablos and K. Rajagopal,, Nucl.Phys.A 1005 (2021) 121904
- *"Impact of LHC jet data on Parton Distribution Functions"*, João Pires, PoS LHCP2020 (2020) 145
- *"Two-particle Correlations in multi-Regge Kinematics"*, N. B. de Leon, G. Chachamis and A. S. Vera, arXiv:2112.13794 [hep-ph]; contribution to Low-x workshop

2 LIP Students Notes

- *"Novel Jet Algorithms to Unveil the Quark-Gluon Plasma Evolution"*, Alexandre Monforte , João Fernandes , Lénea Luís, LIP-STUDENTS-21-08
- *"Understanding Hadronization Timescales Using Jets"*, Diogo Simões and Nuno Madureira, LIP-STUDENTS-21-16

Presentations

8 Oral presentations in international conferences

- Liliana Apolinário: *"Jet Quenching from Light to Dense Systems"*, 2021-02-08, Opportunities of OO and pO collisions at the LHC, CERN (online)
- Guilherme Milhano: *"Electron-Ion Collisions at the LHeC and FCC-he"*, 2021-07-27, EPS-HEP Conference 2021: EPS-HEP 2021, (online)
- Pietro Faccioli: *"NRQCD vs LHC quarkonium production: signs of a deeper J/ψ polarization puzzle?"*, 2021-08-06, A Virtual Tribute to Quark Confinement and the Hadron Spectrum, (online)
- Grigorios Chachamis: *"Rapidity and angular correlations in multi-Regge kinematics"*, 2021-08-27, 10th International Conference on New Frontiers in Physics (ICNFP 2021), (online)
- Nuno Castro: *" EFT studies in the top quark sector (and beyond)"*, 2021-09-02, Energy Frontier Workshop - Restart [Snowmass], online
- J. Pires: *"Status of NNLO QCD corrections for process with one or more jets in the final state at the LHC"*, 2021-09-08, PANIC - Particles an Nuclei International Conference: https://indico.lip.pt/event/592/,
- Grogorios Chachamis: *"Two-particle correlations in multi-Regge kinematics"*, 2021-09-28, Low-x 2021 Workshop, (online)
- Liliana Apolinário, Daniel Tapia Takaki: *"WG5: Heavy-Ions Summary"*, 2021-10-15, 12th International workshop on Multiple Partonic Interactions at the LHC: 12th MPI at LHC, Online

6 Oral presentations in national or international meetings

- Liliana Apolinário: *"Time reclustering for jet quenching studies"*, 2021-01-08, Strong-2020, Jet Observable Workshop, online
- Liliana Apolinário, Urs Wiedemann: *"LPCC Heavy-Ion Working group - Theory Perspective"*, 2021-07-07, Kickoff meeting of the LHC working group on heavy-ions, online
- Carlota Casas: *"In-medium energy loss"*, 2021-08-05, INT Program 21-2b Probing QCD at High Energy and Density with Jets: INT Program 21-2b - , Seattle (online)
- Grigorios Chachamis: *"Factorization and forward production 3rd Meeting on the Forward Physics Facility"*, 2021-10-26, 3rd Meeting on the Forward Physics Facility, (online)
- Grigorios Chachamis: *" Rapidity correlations in multiperipheral models and high energy QCD "*, 2021-11-15, Resummation, Evolution, Factorization 2021 Workshop, (online)
- Pablo Rodriguez: *"Evolution of Initial Stage fluctuations in the Glasma"*, 2021-12-21, V FTAE Christmas Workshop, Granada, Spain

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

- Nuno Castro: *"Probing the Standard Model and Beyond at the LHC"*, 2021-07-15, 6th Lisbon mini-school on Particle and Astroparticle Physics, online

4 Seminars

- Nuno Castro: *"Search for vector-like quarks at the LHC"*, 2021-04-22, CFTP Seminar, online
- Liliana Apolinário: *"Novel jet reclustering tools for heavy-ion collisions"*, 2021-05-20, Relativistic Heavy Ion Group Seminar, Yale University (online)
- Liliana Apolinário: *" Exploring jet time-structure for QGP studies"*, 2021-06-17, Seminar, Institute for Nuclear Theory (online)
- Liliana Apolinário: *" Jet substructure to classify in- medium jet quenching"*, 2021-09-15, HIT-NT Seminar , Lawrence Berkeley National Laboratory (online)

1 Outreach seminar(s)

- Liliana Apolinário: *" Recriar o Big Bang em Laboratório"*, 2021-05-31, XXIV Semana da Física, online

Organized Events

1 International Conferences or Workshops

- *"INT Program 21-2b Probing QCD at High Energy and Density with Jets"*, [Conf-WS-Int] 2021-08-02 / 2021-08-06, Seattle (USA) and online

Theses

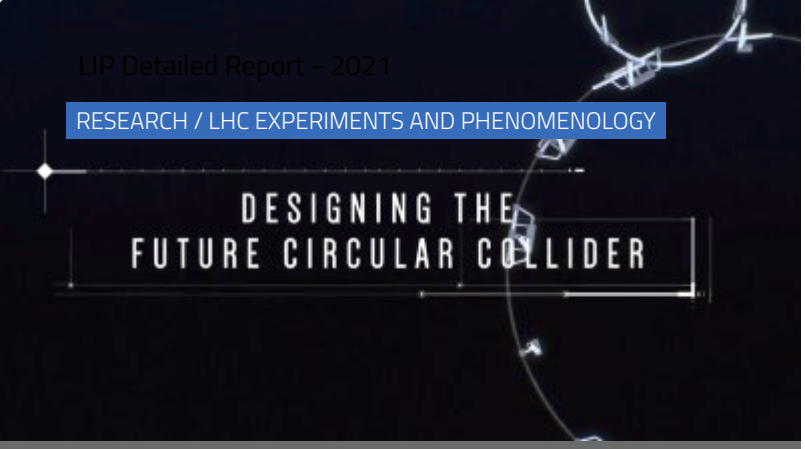
7 PhD

- Maria Ramos: *"Interplay between collider and astrophysical signals of non-minimal composite Higgs models"*, 2017-11-15 / 2022-01-28, (finished)
- Susana Santos: *"Study of the ttH production and Higgs couplings to Top quarks in the ATLAS experiment"*, 2010-10-30 , (ongoing)
- Mariana Araújo: *"Quarkonium production studies at LHC energies: towards the understanding of bound-state formation by the strong force"*, 2018-02-12 , (ongoing)
- Guilherme Guedes: *"Collider and astrophysical constraints to little Higgs models"*, 2018-11-13 , (ongoing)
- João Martins da Silva: *"The substructure of in-medium jets"*, 2021-05-01 , (ongoing)
- João Pedro Gonçalves: *"Disentangling and Quantifying Jet-Quenching With Generative Deep Learning"*, 2021-09-01 , (ongoing)
- Esteban Chalbaud: *"Probing CP couplings in ttX production at the Run3 of the LHC"*, 2021-11-29 , (ongoing)

6 Master

- João Martins da Silva: *"Space-Time Structure of QCD jets"*, 2019-11-20 / 2021-01-28, (finished)
- André Cordeiro: *"Towards the space-time picture of a QCD parton shower"*, 2020-09-01 / 2021-12-06, (finished)
- João Lopes: *"Looking for (de)coherence effects in the Quark-Gluon Plasma"*, 2021-10-01 / 2022-12-31, (ongoing)
- Nuno Madureira: *"Jet substructure tools to identify hadronization timescales"*, 2021-10-01 / 2022-12-31, (ongoing)
- João Humberto Gomes: *"Deep Learning in QCD Jets"*, 2021-10-01 / 2022-12-31, (ongoing)
- Pedro Lagarelhos: *"Prospects for the HL-LHC of the measurement of the top quark couplings in the ttbar semileptonic channel"*, 2018-09-16 , (ongoing)

RESEARCH / LHC EXPERIMENTS AND PHENOMENOLOGY



FCC (*)

Participation in the FCC feasibility study

Principal Investigator:
Ricardo Gonçalo

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

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

(*) As the group has just been created, no FTEs for 2021 are listed

Nat.& Internat. meetings: **2** Oral presentation
Collaboration meetings: **3** Oral presentations
Advanced Training Events: **1** Oral presentation
Seminars: **1** Outreach seminar

Executive summary

The FCC group was recently created to contribute to the ongoing Future Circular Collider (FCC) feasibility study. We hope it will be the seed to the long-term participation of LIP in the FCC endeavour. The group's activities range from detector R&D to theoretical contributions to FCC 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 latest update of the European Strategy for Particle Physics. Current research directions include R&D on new radiation-hard scintillators, detector simulation, and Standard Model parameter calculations relevant for the FCC-ee programme.

This new group fits naturally into LIP's research portfolio, and will eventually become an important component of LIP's participation in CERN, at the forefront of collider-based physics exploration. It has obvious links with the existing LHC-related groups, as well as Computing and several LIP infrastructures, from the Big Data competence centre to LOMaC. We also hope the new group will serve to coalesce research activity in this area, attracting colleagues from outside LIP. For the immediate future, the group has well defined lines of work in detector and theory studies, and plans to grow in scope to encompass other research interests.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Michele Gallinaro		115.000 €	2022-01-01 / 2025-12-31	aAmuse - Project 101006726 / aAmuse - advanced Muon Campus in US and Europe contribution
João Nuno Pires	Ricardo Gonçalo	15.000 €	2022-04-01 / 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. This 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. It will enhance the current energy frontier by an order of magnitude, allowing a future generation of physicists to explore the limits of the Standard Model and possibly reach beyond, to a more fundamental theory.

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.

A small project, already funded by FCT, will allow us to initiate this research activity in the immediate future. Two tasks are defined within this project, on detector R&D and on theoretical studies. The budget will allow us to propose thesis projects based on the FCC programme to a couple of Master students, and to generate interest in this area.

Assessment of the past year: objectives vs. achievements

The group has just been created.

Lines of work and objectives for next year

Two lines of activity are currently defined in the group, focusing on detector development and on theory studies.

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 is done in collaboration with the Institute for Polymers and Composites (IPC), in Minho. We will also become involved in FCC-ee calorimeter simulations, with a PhD student set to spend a few months of her time at CERN working on this. The scintillator work has already started, with first PET scintillator samples produced and awaiting a detailed study. The simulation work is also starting, in collaboration with other teams.

On the theory side, current interest in the group focuses on two areas: higher order electroweak and QCD calculations that will allow the precise determination of the strong coupling constant (a limiting uncertainty affecting EW observable measurements), and the scale evolution of deeply virtual photon scattering processes at the FCC-ee, predicted by the BFKL equation. In fact, the experimental precision envisaged for the FCC-ee must be matched by a similar theory precision, requiring one perturbation order higher than can be currently achieved. Both of these projects are scheduled to begin later this year.

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 currently a small group, built up mostly from researchers already committed to other urgent tasks. But we aim to grow in numbers and breadth of subject in the coming years. 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.

FCC

SWOT Analysis

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 experimental upgrades.

Opportunities

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

Threats

Only shortness of dedicated research time, due to other committments, which may indeed prevent us from making a meaningful contribution.

Presentations

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

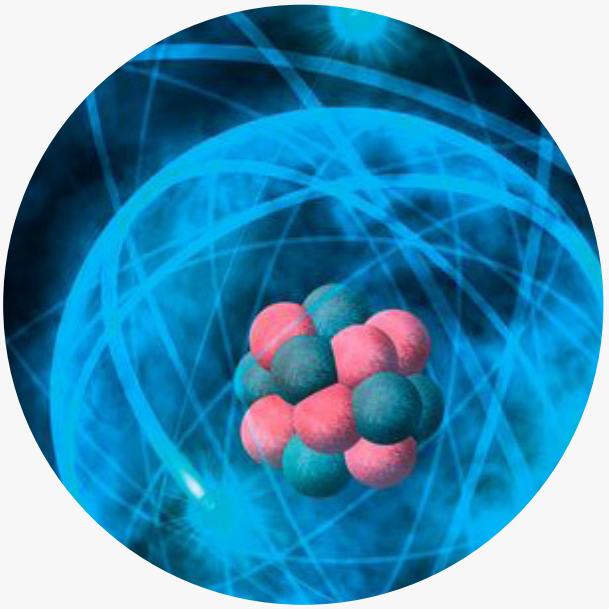
- M. Gallinaro: *"Experimental collaboration: LHC and beyond, a personal view"*, 2021-11-26, FCC Engagement meeting, Lisbon (online)
- R. Pedro: *"Detector Contribution Perspectives"*, 2021-11-16, FCC Portugal Engagement Meeting,

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

- Ricardo Gonçalo: *"Closing Talk: the European Strategy for Particle Physics"*, 2021-11-20, Advanced CERN Portuguese Teachers School, Online

1 Outreach seminar(s)

- Ricardo Gonçalo: *"A fronteira Europeia da Fisica de Particulas"*, 2021-09-24, European Researchers Night, Online



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P&QCD
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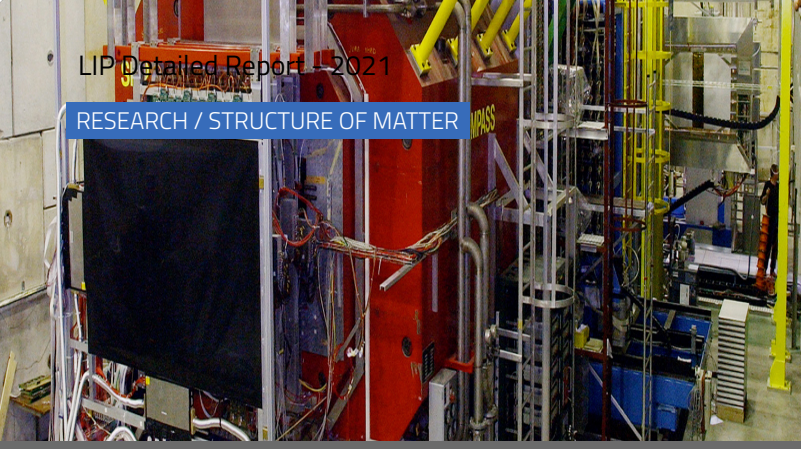


P&QCD

Participation in the COMPASS and AMBER experiments at CERN

Principal Investigator:
Catarina Quintans (100)

3 ***Researcher(s):***
Marcin Stolarski (77), Márcia Quaresma (74), Pietro Faccioli (25)

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

2 ***Master Student(s):***
Catarina Corte-Real (36), Rita Silva (36)

5 ***Undergraduated Student(s) and Trainee(s):***
Francisco Feliciano, Guilherme Almeida, Joana Belo, João Pedro Neves, Pedro Tomé

1 ***External collaborator(s):***
Frantisek Voldrich

Total FTE:
4.5

Articles in international journals:	**1** Direct contribution
Notes:	**1** LIP Students note
International conferences:	**2** Oral presentations
Nat.& Internat. meetings:	**2** Oral presentations
Collaboration meetings:	**12** Oral presentations
Advanced Training Events:	**1** Student presentation

Executive summary

The COMPASS experiment at CERN will have in 2022 its last data taking period, completing the measurement of Deep Inelastic Scattering (DIS) on transversely polarized LiD target, that was started in 2021. The d-quark tensor charge will be measured with an accuracy comparable with the one already achieved by COMPASS for the u-quark, and the uncertainties on the Sivers and Transversity Transverse Momentum Dependent Parton Distribution Functions (TMD PDFs) will be reduced by more than a factor 2.

The beam availability in 2021 was significantly reduced with respect to what was expected. Several technical interventions under CERN responsibility were delayed, mostly due to the COVID-19 pandemic. A series of accidents occurred in the beginning of the Run (including the implosion of a tube for the gas supply of the polarized target system, and an insulation problem at the level of the target cells), causing further delays. The COMPASS physics data taking started by the end of August only, and ended at the beginning of October. The pilot Run for the Proton Radius Measurement of the AMBER experiment followed. In spite of the travel restrictions, the group ensured a permanent presence and expert support to the Detector Control System (DCS), contributed very significantly to the target system, and fulfilled its share of data taking shifts.

As AMBER became a recognized and approved CERN experiment (NA66), during 2021 the Collaboration was established, with by-laws and a collaboration board where the LIP group has a representative. A Memorandum-of-Understanding is presently being prepared. The main responsabilities 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 approches for beam particle identification using the CEDAR (Cherenkov Differential Counter with Achromatic Ring Focus) detectors information. The adaptation 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.

In December 2021, the coordinator of the AMBER Drell-Yan group and member of the LIP group, M. Quaresma, who was under two short term contracts payed from scientific projects (one for COMPASS/AMBER), decided to leave the group and her research career. The group is presently facing a problem of lack of human resources, given the assumed responsabilites. There are presently three students who regularly collaborate in the group, one being a masters student writing a thesis on Drell-Yan measurements at AMBER. During 2021 the collaboration between the LIP Lisbon group and the Aveiro group in COMPASS and AMBER was significantly strenghtened, namely in the tasks related to AMBER simulations.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Catarina Quintans	Carlos Azevedo (UA)	155.000 €	2019-09-01 / 2021-09-30	CERN/FIS-PAR/0022/2019 / Collaboration in the COMPASS and AMBER experiments at CERN
Catarina Quintans	Carlos Azevedo (UA)	165.000 €	2021-10-01 / 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, C. Pires being the responsible for the DCS of both experiments.

The main activity of the group is data analysis. C. Quintans is the coordinator of the COMPASS Drell-Yan physics group. M. Quaresma was co-coordinator of the Drell-Yan physics group of AMBER until end of 2021, but left the group and LIP meanwhile. P. Faccioli, expert in phenomenological studies of Quarkonium, is giving support to the J/psi studies in COMPASS. C. Quintans is one of the analysts working on the Drell-Yan cross-section measurement. She is also responsible for extracting detector efficiencies from 2018 data.

M. Stolarski plays a leading role in the COMPASS analyses related to hadron multiplicities, and is presently evaluating the 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 (Cherenkov Differential Counter with Achromatic Ring Focus).

The group is strongly involved in the preparation of the AMBER Drell-Yan program, by performing physics simulations for phase-I measurements, and in the concept discussions related to the Drell-Yan and Charmonium physics for phase-II. 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. In 2022, COMPASS will have its last data taking period, devoted to semi-inclusive Deep Inelastic Scattering (DIS) on a transversely polarized deuteron target. The AMBER pilot Run for the Proton Radius Measurement shall follow. In this Run, crucial new equipment will be tested, like the Time Projection Chamber, and one or two stations of Silicon Pixel Detectors using the ALPIDE technology. A novel triggerless Data Acquisition System will also be tested for the first time.

Assessment of the past year: objectives vs. achievements

Members of the group contribute to several Drell-Yan and Charmonium ongoing analyses, namely in the aspects of: coordination, co-supervision, and analysis. C. Quintans is the COMPASS Drell-Yan subgroup coordinator. During 2021, the full reprocessing of the data collected in 2018 was completed. The first COMPASS study on the unpolarized Drell-Yan angular dependence was released in April 2021. These results show good compatibility with those published by past Drell-Yan experiments NA10 at CERN and E615 at Fermilab. They confirm a strong modulation in the muon cos(2phi) angle, beyond the expectation from perturbative QCD, that could be interpreted as a hint for the presence of non-negligible non-perturbative effects (the Boer-Mulders transverse-momentum dependent PDF). These studies had direct contributions from C. Quintans and P. Faccioli. The results were presented at several international conferences during 2021. Other analyses, like the J/psi angular dependence and the Drell-Yan and J/psi cross-section measurements, were also expected to have results released in 2021, a goal that was not yet achieved. The extraction of detector efficiencies from different 2018 data periods has shown significant time dependence, that affect the above mentioned analyses. The extraction of these efficiencies for all periods is presently 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 Marcin Stolarski, who focuses on the hadron multiplicities and fragmentation functions (FFs). One of the missing ingredients of the analysis was the estimation of radiative corrections, a major effort which is now being concluded. 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 2021, with the increasing involvement of the students from the LIP group. The cooperation with the Aveiro group in this topic was also strengthened. One student, Rita Silva, has started her Masters thesis, with the study of impact of Silicon vertex detectors in the planned Drell-Yan measurement.

The analysis of CEDARs data collected in 2018 by COMPASS was proceeded in 2021 by Marcin Stolarski and Frantisek Voldrich, a masters student from Czech Republic being co-supervised by M. Stolarski. The beam particle identification by CEDARs is crucial for the feasibility of the AMBER measurements. The first results on the use of neural networks for pattern recognition in CEDARs particle identification detectors (PID) were already shown, and seem a promising approach.

The AMBER Drell-Yan group was coordinated by Márcia Quaresma until the end of 2021. In view of the preparation of the scientific proposal for the phase-II of AMBER, the series of workshops “Perceiving the Emergence of Hadron Mass”, started in 2019, had two remote editions in 2021 (April and September), co-organized by C. Quintans.

The COMPASS 2021 data-taking campaign suffered from a series of delays caused by COVID-19, and a few accidents. As a result, the statistical goals were not achieved, and the data taking will have to continue in 2022. The DCS of COMPASS, a responsibility of the LIP group, was maintained by Christophe Pires and it worked in a stable and reliable way during the whole Run.

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; and the hadron multiplicities produced in semi-inclusive DIS (SIDIS), from 2016 data. Both these analyses should lead to released results during 2022. There are presently two COMPASS papers in drafting stage, to which members of the group contribute directly. These papers shall be concluded and submitted in 2022: one on the topic of double J/psi production in hadron-hadron collisions; and another on the pT dependence of hadron multiplicities from SIDIS.

The studies concerning hadron beams for the AMBER measurements, both conventional and radio-frequency separated, are contributed by C. Quintans, together with the CERN Beam Department and others. These should lead to the publication of a paper in 2022, which is presently in drafting stage. The results are also important for the preparation of the AMBER proposal for phase-II measurements. The proposal is being prepared, and a present goal is to have its first version submitted until the end of the year.

The studies on the use of neural network methods for beam particle identification using CEDAR detectors information shall be continued by M. Stolarski and F. Voldrich. The results will be the content of the Master Thesis of Frantisek Voldrich, to be presented at the Czech Technical University in Prague, in the Summer of 2022. This thesis is co-supervised by M. Stolarski.

The studies on the impact of the future Silicon Vertex Detector in the Drell-Yan measurement of AMBER and optimization of the setup are the subject of Rita Silva's Master thesis. Two main options will be investigated: a new Silicon Pixels detector based on the ALPIDE technology; and the re-use of a Silicon microstrips detector, the FVTX from the PHENIX experiment at RHIC. The thesis shall be presented in the Summer 2022 to the Instituto Superior Técnico of Universidade de Lisboa, and is co-supervised by C. Quintans.

COMPASS will have its last data taking period in 2022. This is the last opportunity to collect the proposed 140 days of good physics data (combined 2021+2022), that shall allow to reach the goal in terms of statistics. The AMBER pilot Run for the Proton Radius Measurement, should take place most likely in October. New equipments will be tested, like the Time Projection Chamber (TPC), and the Silicon Pixel Detectors. The new DAQ system will run in triggerless mode, also for the first time.

C. Pires is candidate to the COMPASS 2022 Run co-coordination. This task requires high technical competences. Being an expert and main responsible for the DCS, and simultaneously one of the target system experts in COMPASS, C. Pires is highly qualified for this task.

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 and the hadron multiplities on hydrogen target measurement. Once the COMPASS data taking is completed, a change-over to the AMBER setup of the Proton Radius Measurement should happen. This observable will be accessed from the high-energy muon-proton elastic scattering process. The main parts of the planned setup are an active TPC filled with high pressure hydrogen serving as target and recoil detection medium, and very fine granularity silicon pixel detectors (ALPIDE technology) for the tracking of the small angle kink to the scattered muon. These two new equipments will be complemented by several other COMPASS detectors also used in the setup. The control of this new detector will require a new Detector Control System, that will partly inherit from the COMPASS DCS. The LIP group will take the responsibility for the AMBER DCS, possibly in cooperation with another AMBER group.

The Drell-Yan measurements at AMBER are a main physics interest for the LIP group. The phase-I measurements, already approved, may start in 2024. They require a novel vertex detector concept, a more precise beam reconstruction (possibly with additional detectors), and a beam particle identification system (CEDARs based) that provides good efficiency and purity. These topics are being studied by the group. In parallel, the group shall continue 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. At the end of 2021, M. Quaresma left the group and LIP, at a time when her contract could only be 50% covered by the COMPASS/AMBER scientific project funds. Although the problem had been anticipated, no good solution could be found. Two other researchers in the group will face the same employment instability difficulties in the coming years. The small dimension of the group is presently a limiting factor in the activities we develop. The present number of senior collaborators does not allow for further students supervision, beyond the three already integrated.

Opportunities

The approval 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 three young students are presently contributing.

Threats

The precarious employment situation of some members of the group continues to be a serious threat. Although the COMPASS/AMBER project was recently funded for the next two years, the shared costs of setting up a new experiment go much beyond what this project budget can cover. The signing of the AMBER Memorandum of Understanding must still be negotiated, and alternative financial solutions must be explored.

P&QCD

Publications

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

- *"The large COMPASS polarized solid ammonia target for Drell–Yan measurements with a pion beam"*, V. Andrieux, C. Pires, C. Quintans et al , NIM A 1025 (2022) 166069

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

- *"Spin density matrix elements in exclusive ω meson muoproduction"*, G.D. Alexeev et al (COMPASS Coll.), Eur. Phys. J. C (2021) 81:126
- *"Triangle Singularity as the Origin of the a1(1420)"*, G.D. Alexeev et al (COMPASS Coll.), Phys.Rev.Lett. 127, 082501 (2021)
- *"Probing transversity by measuring Lambda polarisation in SIDIS"*, G.D. Alexeev et al (COMPASS Coll.), Phys.Lett. B 824 (2022) 136834
- *"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 LIP Students Note(s)

- *"What are nucleons and pions made of?"*, Guilherme Almeida and Pedro Tomé, LIP-STUDENTS-21-35

Presentations

2 Oral presentations in international conferences

- Catarina Quintans: *"New experimental results on the (spin) structure of the nucleon"*, 2021-09-09, PANIC - Particles an Nuclei International Conference: PANIC 2020 -- The 22nd Particles and Nuclei International Conference, Lisbon, Portugal (remote)
- Catarina Quintans (on behalf of the AMBER Coll.): *"New M2 beamline at the CERN SPS"*, 2021-10-18, The 2021 School on the Physics of Baryons -- Baryons-21_School, Seville, Spain (remote)

2 Oral presentations in national or international meetings

- Márcia Quaresma (on behalf of AMBER Coll.): *"Physics motivations for Drell-Yan with K+/K- beams"*, 2021-09-30, RF-Separated beams for AMBER -- Kick off meeting, CERN (remote)
- Márcia Quaresma (on behalf of AMBER Coll.): *"Beamline specifications for Drell-Yan with K+/K- beams"*, 2021-09-30, RF-Separated beams for AMBER -- Kick off meeting, CERN (remote)

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

- G. Almeida and P. Tomé: *"De que são feitos os nucleões e os piões?"*, 2021-09-14, LIP Internship Program 2021,

Organized Events

2 International conference(s) or workshop(s)

- Perceiving the Emergence of Hadron Mass - EHM V, online, 2021-04-27 to 2021-04-30
- Perceiving the Emergence of Hadron Mass - EHM VI, online, 2021-09-27 to 2021-09-29

Theses

1 Master

- Rita Silva: *"Optimisation studies for the pion-induced Drell-Yan measurement at the AMBER experiment"*, 2021-11-14 , (ongoing)

HADES

Collaboration in the HADES experiment at GSI

Principal Investigator:
Alberto Blanco (20)

1 ***Researcher(s):***
Paulo Fonte (10)

2 ***Technician(s):***
João Saraiva (10), Luís Lopes (10)

1 ***Undergraduated Student(s) and Trainee(s):***
Guilherme Alcides Rodrigues

Total FTE:
0.5

Articles in international journals:	**2** Indirect contribution
Collaboration meetings:	**2** Oral presentations
Advanced Training Events:	**1** Student presentation

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, the group was complemented with people from LIP-COMPASS group for the analysis of the data produced by the HADES detector. This synergy has 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. Recently, the group has lost the people involved in data analysis (due to other commitments) and has been reduced again to hardware activities, which are now complemented, beyond the operation of the RPC-TOF-W, with the construction of a new TOF detector for the HADES forward region, the RPC-TOF-FD, and a strong collaboration with the Multi Drift Chamber (MDC) group with the aim of preparing the HADES tracking system for FAIR.

Despite the current pandemic situation, the proposed work plan for 2021 was almost fully accomplished. One particular highlight was the beam test of the first two modules of the RPC-TOF-FD and the finalization of the construction and installation of the complete system at the GSI. Although the test was not completely successful, the necessary actions have been taken to ensure that the detector will perform according to expectations for the next production run in February 2022.

The group activities are financially supported by a modest quantity in the framework of a MoU signed between HADES and FCT and complemented by a strong support from HADES in terms of travel and accommodation as well as detector components.

One student collaborated in the RPC-TOF-FD construction and test in the framework of the LIP Summer Internship Program. The effort to attract students to the group will continue.

HADES

Overview

Presently, only the hardware-related line of work is still active with the following sub-lines:

- **RPC-TOF-W upgrade and operation.** Upgrade of the RPC-TOF-W and operation within the data taking periods and collaboration on general duties related to data taking periods as HADES DAQ operator and shift leader. Responsibility: A. Blanco, P. Fonte, L. Lopes and J. Saraiva
- **Design and construction of the RPC-TOF-FD.** In order to increase the acceptance of the spectrometer, a new detector, to cover the very low polar angles in the forward region, is being constructed. This new Forward Detector (FD) is composed by a tracking detector and a TOF detector. The LIP group is in charge of the simulation, design and construction of the TOF detector of the FD, RPC-TOF-FD. 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 as follows (directly copied from previous report):

- Beam test of the RPC-TOF-W (equipped with new DAQ system) with all HADES systems in operation.
- Beam test of the two RPC-TOF-FD modules with the aim to test the count rate capability in HADES environment and commissioning partially the system.
- Construction of the two + one (spare) modules of FD, test them with cosmic rays in Coimbra and install two of them in HADES in the second semester of 2021.
- Continue to attract students to the project in the framework of LIP Summer Internship Programme or by proposing MSc theses.
- As in 2020, but hopefully with a better chance of being accomplished: continuation of the tests carried out with Lenav2. Integration of the new electronics in some of the HADES planes/sectors and subsequent test. Maintenance of the gas systems of the tracking system.

The planned test beam to evaluate the performance of the RPC-TOF-W equipped with the new DAQ system took place in February 2021 (the old RPC-TOF-W system, based on TRB2 boards, imposed limitations to reach the target HADES acquisition rate of more than 200k events/sec.). One week of data was collected, allowing the detector to be evaluated and re-calibrated. The results showed that the RPC-TOF-W is ready for production beam with the new DAQ system, with the same performance as before.

In the same test beam the first two RPC-TOF-FD modules were exposed to p+p collision at 4.5 GeV to assess the performance and the count rate capability of the detector in real conditions. The performance, mainly, timing resolution and efficiency, was evaluated showing at moderate rate a good agreement with the values measured with cosmic rays in laboratory conditions. However, at nominal rate, the inner part of the detector (close to the beam axis) suffered from saturation due to an excess of particle load. After an analysis of the acquired data, it was concluded that this saturation was due to two main reasons. On the one hand, the detector was placed too close to the beam axis, resulting in an excessive irradiation of the primary proton beam. This is easily solved by moving the detector apart in the radial dimension. On the other hand, even after correction of the position, the measured particle load around the beam axis exceeds the expected value by a factor of 4 (from 0.4 kHz/cm² to 1.5 kHz/cm²). This particle load, which exceeds the rate capability of the detector, will be accommodated by increasing the working temperature of the detector by 15°, which will provide the extra rate capability to measure a particle rate of 1.5 kHz/cm² due to the decrease of the glass resistivity.

This forced us to prepare during 2021 a heating system for the detector. The system is based on hot water circulation through copper pipes and a PID control provided by the CCCM. The temperature of the detector is maintained within 0.5 ºC in the approximately 4 m² of the detector.

The two remaining FD modules (spare module has not been built yet) were built at Detector Laboratory and tested successfully with cosmic rays before shipping to GSI. The commissioning of the entire system at GSI took place at the end of the year.

Unfortunately, due to the present pandemic situation the planned activities together with the MDC group did not take place. They were limited only to consulting and maintenance of the gas system of the tracking system.

One student joined the group (for a couple of weeks) in the framework of the LIP Summer Internship Program to help on the construction and test of the RPC-TOF-FD modules.

Lines of work and objectives for next year

- 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, where the performance of the system will finally be fully evaluated. This will demonstrate the feasibility of increasing the

count rate capability of an RPC detector by increasing the 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 system with the aim of increasing the longevity of the system.

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 incorporating 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 is focused in our main three lines:

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

SWOT Analysis

Strengths & opportunities

- The skills and accumulated know-how on the construction of RPCs allowed us to build a detector able to run within specifications and flawlessly during all campaigns, and which probably is the detector of its kind with best performance in the world.
- The excellent work developed during the years gave us the opportunity to build a new detector for the collaboration, the new TOF-FD.
- The performance and reliability demonstrated by the RPC-TOF-W is a good recommendation letter for other experiments. Hopefully, the RPC-TOF-FD will join, demonstrating the viability of increasing the count rate capability of an RPC detector by increasing the operating temperature.

Weaknesses & threats

- The reduced number of team members and their commitments with other projects.
- The lack of funding may strongly compromise all the group activities.
- The loss of the data analysis component weakens the group.
- The difficulty to attract resources (students and funding) to HADES.

HADES

Publications

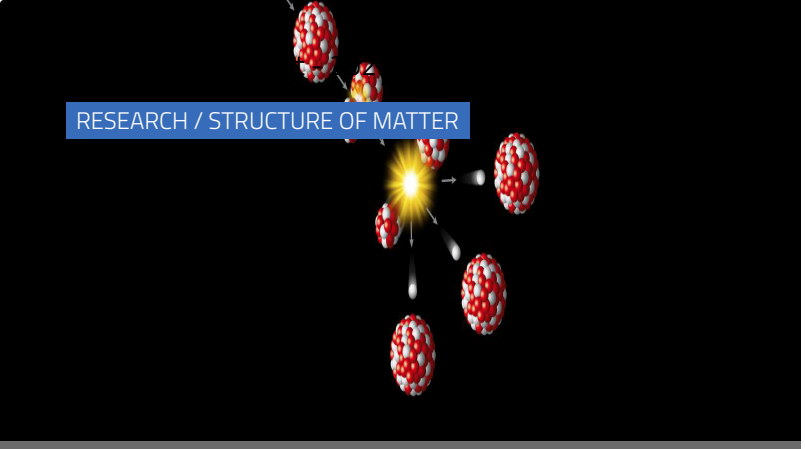
2 Articles in international journals (with indirect contribution from team)

- *"Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR"*, HADES collaboration PANDA (130 authors), Eur. Phys. J. A 57 (2021) 138
- *"Correlated pion-proton pair emission off hot and dense QCD matter"*, HADES collaboration (122 authors), Phys. Lett. B 819 (2021) 136421

Presentations

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

- Guilherme Alcides Rodrigues: *"Testes do novo detetor de tempo de voo para experiência HADES"*, 2021-09-14, LIP Internship Program 2021, Online



NUC-RIA

Nuclear Reactions, Instrumentation and Astrophysics

Principal Investigator:
Daniel Galaviz (65)

6 ***Researcher(s):***
Alberto Blanco (6), Jorge Sampaio (15), José Pires Marques (86), Luis Peralta (30), Pamela Teubig (55), Paulo Velho (100)

2 ***Technician(s):***
João Saraiva (3), Luís Lopes (3)

3 ***PhD Student(s):***
Carina Coelho (6), Elisabet Galiana (100), Manuel Xarepe (100)

6 ***Master Student(s):***
Francisco Barba (100), João Jantarada (78), Lia Pereira (6), Ricardo Silva (77), Rita Pestana (50), Tomás Correia Sousa (50)

4 ***Undergraduated Student(s) and Trainee(s):***
André Azevedo, Débora Almeida, Maria Alves Simões, Ricardo Pires

1 ***External collaborator(s):***
Ana Isabel Henriques

Total FTE:
9.3

Articles in international journals:	**4** Direct contribution **2** Indirect contribution
Preprint:	**1** Preprint
International conferences:	**1** Oral presentation
Nat.& Internat. meetings:	**2** Oral presentations
Collaboration meetings:	**1** Oral presentation
Completed theses:	**2** MScs

Executive summary

Despite the fact that the pandemic continued to impose limits to our activities, 2021 was a year of growth for the group, with the consolidation of its two main lines of research linked by the common ground of the study of Nuclear Reactions for fundamental research: Nucleon-Nucleon interaction studies at relativistic energies, and Nuclear Astrophysics. We highlight the following topics:

- Installation of a ToF-RPC detector for relativistic protons at R3B/FAIR: In a joint effort with the RPC group at LIP-Coimbra, we have installed a large area RPC wall in the R3B experiment (Reactions with Relativistic Radioactive Beams) at the FAIR facility at GSI. The detector was installed in December 2021 and is now ready to take data in the experiments scheduled within the so-called Phase-0 of FAIR. The installation, control, integration and use of the RPC are within the scope of the PhD thesis of Manuel Xarepe, who will also focus on the analysis of short range correlations in nuclei, a measurement that will be performed in 2022. In 2021, funding from FCT was secured for this experimental program.
- Proposal and approval of elastic scattering experiment at HIE-ISOLDE: In the framework of an international collaboration of about 20 institutes throughout Europe, the group lead the submission and defense of an experimental proposal to study for the first time the angular distribution of elastic scattering alpha particles on radioactive nuclei at the ISOLDE laboratory at CERN. The proposal was recommended for beam time allocation. This experiment, in close collaboration with groups in the University of Seville and Huelva (Spain) was the seed for sucessful request of funds at the CERN/FCT funding scheme.
- Consolidation of local reaction studies for Nuclear Astrophysics: The measurement of low energy proton-capture reactions using the activation technique and the detection of emitted X-rays was consolidated for the cases ^{118}Sn(p,gamma$^{)119}$Sb and ^{116}Sn(p,gamma)^{117}Sb. This opens now the scope for further measurements at the local facility in Lisbon. In addition, the use of nuclear reaction network codes has considerably advanced, providing a tool to quantify the impact of the measured reactions under nucleosynthesis conditions.
- Collaboration with ERC-Grantee for Kilonova physics: The collaboration with the group of Prof. Martinez Pinedo at the TU-Darmstadt in the context of the ERC funded Kilonova project on the description of absorption curves of lanthanides and actinides in the spectra observed after Neutron Star mergers events was consolidated during 2021. In this framework, the master thesis of Ricardo Silva was successfully concluded, providing the opening for a new line of research within the topic of Nuclear Astrophysics.
- Integration in the Euro-Labs Infrastructure consortium: The group followed the application by the major nuclear physics laboratories in Europe to the call open by the Horizon Europe program. The consortium Euro-Labs, approved recently, will be an important instrument to support the participation of group members in experiments at the various facilities that are part of the consortium. A supporting group for the production and characterisation of targets for nuclear reaction experiments was created within the consortium. Our main goal is to reinforce our capabilities in the production of thin targets for nuclear reaction experiments.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Daniel Galaviz	Alberto Blanco	49.874 €	2021-10-15 / 2023-04-14	EXPL/FIS-NUC/0364/2021 / Short range CORelations on Exotic nuclei at R3B/FAIR using tRPCs
Daniel Galaviz	A.M. Sanchez-Benitez (UHuelva)	20.000 €	2022-04-01 / 2024-03-31	CERN/FIS-PAR/0009/2021 / RENASCER_Estudos de reações nucleares para Astrofísica Nuclear na instalação ISOLDE do CERN

NUC-RIA

Overview

The activity of the group is oriented to the experimental study of nuclear reactions, divided into two 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.

Focusing on these two lines, the group successfully managed to secure funds at national and international level. Our goal is now to strengthen the presence of LIP in low and high-energy nuclear radioactive beam facilities (mainly in Europe). At LIP, the interdisciplinary field of Nuclear Astrophysics now holds experimental and theoretical expertise that we expect will reinforce the laboratory in the field.

The group, still under the leadership of Daniel Galaviz, had a significant growth in critical mass, with a total of 6 PhD researchers, 3 PhD students, and 6 master atudents. We are located mainly at the Faculty of Sciences of the University of Lisbon, where the direct contact with students at the various levels shows a strong potential for attraction and interaction.

Assessment of the past year: objectives vs. achievements

Below we compare the goals for 2021 with what was accomplished:

Experimental activity at R3B/FAIR

During Spring 2021, in the framework of the Phase-0 experimental campaign at FAIR, the goal of participating in R3B experiments was achieved, in spite of the constraints imposed by the pandemic, through remote contribution.

Towards the end of the year, in collaboration with the RPC group, a new detection system based on the RPC technology was installed at the R3B setup. The goal is to measure with high precision (about 1%) the momentum of protons emitted in reactions within the R3B experiments using the Time-of-Flight technique. This is the start of an activity that we expect to become a long term topic within the group. The group secured funds for this activity through the approval of an exploratory project submitted to FCT. In addition, this line of research is at the centre of the PhD thesis of Manuel Xarepe, started in October 2021.

Nuclear astrophysics activities

Our activity in this physics topic experienced a considerable growth in 2021, both in number of people (three new senior members and one master student) and in the variety of topics addressed. Here we list the activities performed:

- Proposal and approval of a reaction experiment at ISOLDE/CERN: The group lead the preparation, submission and defense of an experimental proposal to measure for the first time the elastic scattering reaction of alpha particles with radioactive nuclei. The experiment was approved and should be scheduled in the near future. The group has also secured funds for this research line through an approved project submitted to the FCT/CERN funding scheme.
- Atomic structure calculations for Kilonova physics: The group has been reinforced with the addition of new members (J.P. Marques, J. Sampaio, R. Silva) working on the systematic calculation of atomic parameters (oscillator strengths, excitation and ionisation cross sections) needed to model the light-curves of the kilonova electromagnetic transient associated with neutron star mergers. In particular we are interested in the whole line of lanthanides and actinides (for various charge states) where there is strong evidence that they are being r-processed in kilonovas, but for which there are large gaps in atomic data. In the context of R. Silva's Master's Thesis we calculated opacities for Nd III and U III in LTE (local thermodynamical equilibrium) using the code FAC (Flexible Atomic Code). This line of work established a collaboration with the Nuclear Astrophysics group led by G. Martinez-Pinedo at the GSI/FAIR laboratory.
- Activation experiments at CTN: The experimental activity around the measurement of (p,gamma) reactions using the activation technique through the measurement of X-ray yields was not completely developed as foreseen for 2021. The pandemic, the reduced accessibility to the local accelerator, and the reallocation of human resources to other activities had a significant impact on this topic.
- Reaction Network calculations for stellar nucleosynthesis: This research topic continues expanding within the group, aiming at providing a research tool that will allow for the identification of nuclear properties relevant for stellar nucleosynthesis scenarios. The master student Afonso Jantarada continued working along this line.

Detector activities

The group had also planned for 2021 to work on two topics in instrumentation for fundamental science, which did show progress:

- Silicon detector thickness characterisation: In the framework of a reaction experiment performed at the LNS/INFN laboratory in Catania (Italy), the analysis of the measured data allowed for a precise characterisation of the effective thickness of thin (20 um) Single-Sided Silicon Strip Detectors (SSSDs). Francisco Barba has performed and concluded this work in the framework of his master thesis.
- RPCs for fast neutron measurements: in collaboration with the RPC and the Neutron Detectors groups, we gave contributions to simulations and data analysis of fast neutron detection using boron-coated RPCs.

Meetings in Lisbon

The group actively contributed to international meetings planned in Lisbon. We organised the final General Assembly and Workshop of the COST Action ChETEC (Chemical Elements as Tracers for the Evolution of the Cosmos), in a hybrid format, in September 2021. About 40 participants were in person in Lisbon, with a total participation of about 100 people. In addition, the group took responsibilities in LIP outreach activities.

Lines of work and objectives for next year

The lines of work we foresee for 2022 imply a natural continuation of those started last year, with some room for expansion, but caution at the same time.

- Experiments at R3B: We are immersed in the preparations for the experimental campaign of the R3B collaboration for 2022. The students Manuel Xarepe (PhD) and Tomás Sousa (MSc) are currently at the GSI/FAIR facility, participating on those preparatory works. We foresee the contribution of other members of the group to this activity, either locally or remotely. Manuel will continue his stay in Germany in the framework of his PhD project. Tomás will then focus on the preparation and execution phases of the experiments, closely working with the CALIFA electromagnetic calorimeter.
- Preparation of ISOLDE experiment IS698: Under the acronym attributed to the approved ISOLDE experiment, we will work on the planning and preparation of the experiment devoted to the measurement of the elastic scattering of radioactive nuclei on alpha particles at ISOLDE. The angular distribution of the alpha particles scattered off ^{108}Sn and ^{110}Sn will be measured by a setup of position-sensitive silicon strip detectors that will cover the whole experimental angular range. The preparation of all components of this project (mechanics, electronics, DAQ) will start in 2022, while we wait for the confirmation of beam time scheduling. This will be the main topic of the PhD thesis of Francisco Barba, who is currently finishing his MSc thesis.
- Atomic Physics and Kilonova: Followed by the start of the collaboration with the ERC granted last year, and considering the rising interest of the nucleosynthesis r-process modelling community on the type of calculations performed by the group, during the next year we intend to complete the calculation of the energy lines and oscillator strengths for all relevant elements and charge states.
- Low-energy nuclear reactions: We plan to reactivate the research program around the measurement of low-energy (p,gamma) reactions for Nuclear Astrophysics applications. Measurements will predominantly run at the local facility at the CTN/IST campus. The existence of a consortium at the European level, supporting the access of experimentalist to nuclear accelerator laboratories for the execution of experiments in the field of Nuclear Astrophysics (ChETEC-Infra) will open the door for the execution of experiments in other facilities. The planning of research proposals in European laboratories will start in 2022. Complementarily, the modelling of nuclear reaction networks for nucleosynthesis will continue. Along these lines, Afonso Jantarada (reaction networks) and Ricardo Pires (low-energy measurements) will develop their master theses.
- Outreach: We plan to contribute to traditional outreach activities, namely the IPPOG Masterclasses at FCUL and the involvement in the LIP Internship Programme.

Medium-term (3-5 years) prospects

In the short term, the group has funds for its two main lines of research: reaction experiments and instrumentation at FAIR; and reaction experiments at ISOLDE. It is our goal to work towards the growth in these two lines, reinforcing at the same time the research in the field of Nuclear Astrophysics. The work on Kilonova physics has received a lot of attention, and has the potential for expansion in the mid-term.

The group must focus on the execution of the planned experiments, while trying to consolidate the research activity at the different host labs and infrastructures, with the goal of officially joining the relevant scientific collaborations.

SWOT Analysis

Strengths

involvement in international collaborations. Knowledge in nuclear instrumentation, data analysis, particle transport simulations, and nuclear astrophysics. Participation over the years in experiments performed in various radioactive and stable beam accelerator institutes. Ability to expand present collaborations to other institutes. Strong capability to attract students.

Weaknesses

Despite the recent successes, funding is still very limited. This lack of funds may affect the possibility to effectively contribute to the construction of new detection systems in the international collaborations the group is involved in.

Opportunities

The involvement of the group at the international level opens the opportunity for visibility and attraction of young researchers. The participation in various consortia (EUROLabs, ChETEC-Infra, the submitted COST action NCAP in the field of Nuclear Astrophysics) remains an opportunity for growth.

Threats

The possibility to effectively contribute to the next generation facilities like FAIR or ISOLDE is presently real. If the group does not manage to execute such contribution, future participations in these facilities and in the frontier physics they will address are under threat.

NUC-RIA

Publications

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

- *"Fundamental Parameters Related to Selenium Kα and Kβ Emission X-Ray Spectra"*, Mauro Guerra, Jorge M. Sampaio, Gonçalo R. Vília, César A. Godinho, Daniel Pinheiro, Pedro Amaro, José P. Marques, Jorge Machado, Paul Indelicato, Fernando Parente, José Paulo Santos, Atoms 9,8 (2021)
- *"Peeling graphite layer by layer reveals the charge exchange dynamics of ions inside a solid"*, Anna Niggas, Sascha Creutzburg, Janine Schwestka, Benjamin Wöckinger, Pedro L. Grande, Bernhard C. Bayer, José P. Marques, Friedrich Aumayr, Robert Bennett, Richard A. Wilhelm, Communications Physics 4, 1801 (2021).
- *"Fluorine depth profiling based on the F-19(p,p'gamma)F-19 excitation function"*, J. Cruz, M. Fonseca, D. Galaviz, A. Henriques, H. Luis, J. Machado, P. Teubig, P. Velho, V. Manteigas, A. P. Jesus, Eur. Phys. Journal Plus 136, 969 (2021)
- *"NeuLAND: The high-resolution neutron time-of-flight spectrometer for R3B at FAIR"*, K. Boretzky, I. Gasparic, M. Heil, et al. (91 authors) for the R3B collaboration, Nucl. Instr. and Methods A 1014, 165071 (2021)

1 Preprint(s)

- *"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, arXiv:2111.11786v1

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

- *"Probing proton halo effects in the B-8+Zn-64 collision around the Coulomb barrier"*, R. Sparta et al. (23 authors), Phys. Lett. B 820 (2021) 136477
- *"First beta-decay spectroscopy of In-135 and new beta-decay branches of In-134"*, IDS Collaboration (93 authors), Phys. Rev. C 101 (2021) 044328

Presentations

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

- M. Xarepe, F. Barba, D. Galaviz, L. Peralta, R. Pires, J. M. Pires-Marques, J. Sampaio and P. Teubig: *"Determination of 118Sn(p,g)119Sb cross-section at astrophysical energies from X-ray emission yields "*, 2021-09-05, PANIC - Particles an Nuclei International Conference: PANIC 2021, Online

2 Oral presentations in national or international meetings

- Ricardo F. Silva, Jorge Sampaio, Pedro Amaro, José Pires Marques: *"Atomic Structure Calculations in Lanthanide and Actinide ions relevant to kilonovae"*, 2021-05-16, Virtual workshop on the "Atomic Structure of Actinides & Related Topics" 26-28 May 2021 , online
- Ricardo F. Silva, Jorge Sampaio, Pedro Amaro, José P. Marques: *"Atomic Structure Calculations in Lanthanide and Actinide ions relevant to kilonovae"*, 2021-09-09, ChETEC COST Action, Sep 8-10, 2021, Hotel Sana Malhoa, Lisbon & online

Theses

3 PhD

- Elisabet Galiana: *"Analysis and simulation of (p,g) and PIGE low energy reactions: An ENSARRoot developmen"*, 2018-01-01 , (ongoing)
- Carina Coelho: *"The effects of proton therapy on protein self-organization: potential benefits for neurodegenerative disorders"*, 2021-10-01 , (ongoing)
- Manuel Xarepe: *"Measurements of Short Range Correlations on Exotic Nuclei at R3B using TRPCs"*, 2021-10-01 , (ongoing)

7 Master

- Manuel Xarepe: *"Determination of 11Sn(p,y)11Sb cross-section at astrophysical relevant energies from X-ray yields"*, 2019-10-01 / 2021-01-29, (finished)
- Ricardo Silva: *"Atomic structure calculations in lanthanide ions relevant to kilonovae"*, 2021-03-24 / 2021-12-07, (finished)
- Francisco Barba: *"Characterization of thin silicon strip detectors for nuclear experiments"*, 2020-09-01 , (ongoing)
- Tomás Correia Sousa: *"Characterization of CsI(Tl) Crystals and Implementation of tools for the CALIFA calorimeter at FAIR "*, 2021-10-01 , (ongoing)
- Lia Pereira: *"Modelling protein amyloid structures and observing the effects of radiation using the GEANT4-DNA toolkit"*, 2021-10-04 , (ongoing)
- João Jantarada: *"Simulation of a p-process in a Supernova Explosion using the NucNet Tools framework."*, 2021-10-01 , (ongoing)
- Rita Pestana: *"Development of a standard methodology for online dose calculation in air "*, 2021-10-01 , (ongoing)

NPSTRONG

Nuclear Physics and Strong Interaction Group

Principal Investigator:
Teresa Peña (100)

4 ***Researcher(s):***
Alfred Stadler (100), Ana Arriaga (25), Elmar Biernat (10), Gernot Eichmann (100)

1 ***PhD Student(s):***
Raúl Torres (100)

3 ***Master Student(s):***
André Torcato (100), Eduardo Ferreira (100), Madalena Lourenço (2)

3 ***Undergraduated Student(s) and Trainee(s):***
André Nunes, Heitor Österdahl, Mário Amaro

Total FTE:
6.4

Articles in international journals:	**2** Direct contribution
International conferences:	**6** Oral presentations
Advanced Training Events:	**5** Oral presentations
Seminars:	**2** Seminars
Completed theses:	**3** MScs

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.

We work on a variety of topics addressing nonperturbative phenomena in quantum field theories with computational methods, in particular Quantum Chromodynamics (QCD). This includes the internal structure of mesons and baryons and 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 challenge our understanding of the strong force. The fundamental 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 such as heavy-ion collisions and 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.

In 2021, NPstrong continued to consolidate its research in theoretical nuclear and hadron physics at LIP. We have been exploring new research directions, which have considerably expanded the portfolio of the group and will open the doors towards new research areas in the future.

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).

Sources of funding

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

NPstrong

Overview

The group NPstrong currently consists of five senior members (three of them permanent), one PhD student and two master students. The main lines of research aim at a theoretical understanding of QCD from first principles at the interface of hadron and nuclear physics:

- 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.
- Multiquark systems.
- The muon anomalous magnetic moment.

Assessment of the past year: objectives vs. achievements

In 2021, NPstrong continued to consolidate its research in theoretical nuclear and hadron physics at LIP. We have been exploring new research directions, which have considerably expanded the portfolio of the group and will open the doors towards new research areas in the future:

- A new PhD student was hired through a CERN-PT grant to work on pentaquarks.
- Two master students successfully defended their theses, and one master student recently submitted his thesis;
- Two students completed a project within the LIP Summer Internships.
- Teresa Peña and Gernot Eichmann became associate members of HFHF, Helmholtz Forschungsakademie Hesse fur Fair, a German think tank for FAIR physics.
- Gernot Eichmann became the LIP spokesperson for HFHF.
- Teresa Peña co-organized the "2021 School on the Physics of Baryons".

In the following we highlight the main scientific achievements of the year 2021:

Hadrons on the light front: In the course of a master thesis, we developed a novel method to compute hadron properties on the light front by employing contour deformations in the complex plane. As a first application, we calculated light-front wave functions; the next steps are to compute parton distributions with functional methods, thereby establishing close ties with experimental efforts at the future Electron Ion Collider. The master student who performed the work (Eduardo Ferreira) completed his studies with the highest possible grade, and the corresponding paper was selected for an Editor's Suggestion to be featured on the Phys. Rev. D website.

Ab-initio calculations for gluons: We made substantial progress in ab-initio solutions of the Yang-Mills sector of QCD, i.e., QCD with gluons only but without quarks. This provides a glimpse into the underlying mechanisms of confinement and dynamical mass generation for gluons. We demonstrated the equivalence of the solutions obtained with functional methods and those from lattice QCD, with a truncation error at the 3-4% level, and we identified a possible order parameter for gluon mass generation. This will serve as the starting point for genuine ab-initio calculations for hadron properties also with dynamical quarks in the future.

Pentaquarks: In the course of a master thesis (completed by Madalena Lourenço), we computed the spectrum of heavy-light pentaquarks in view of the LHCb pentaquarks, including their pole positions in the complex momentum plane. While the scope of the thesis was rather exploratory, we have meanwhile extended the calculations to compute all couplings in the system dynamically. In 2021 a PhD student from Mexico (Raul Torres) received a CERN-PT Grant and joined our group; the goal of his PhD thesis is to calculate the properties of pentaquarks from a genuine five-body equation.

Baryon spectroscopy: Within a master thesis (recently submitted by André Torcato), we computed the spectrum of heavy baryons using functional methods. We employed a quark-diquark approach that has proven successful in the light-baryon sector. The goal of this work is to shed light on the newly discovered states at LHCb, in particular those with different flavors.

Meson spectroscopy: We aim for a comprehensive description of meson properties in the Covariant Spectator Theory (CST) by implementing a dynamically obtained quark mass function. Progress this year was made in our understanding of the dynamical quark mass component determined by the gluon pole and the role of the finite mass of the gluon.

The scientific achievements described above match with the objectives stated previously for the year. The only deviation concerns machine learning with functional methods, where the student assigned to the project had to focus on other commitments as he is currently doing an Erasmus stay in Italy.

Lines of work and objectives for next year

In 2022 we expect to continue our strategy of sustained growth, which includes the need for attracting master and PhD students. We aim to continue providing high-impact results with international recognition and maintaining close ties to experimental efforts at LHCb, ALICE, COMPASS, 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 in order to consolidate the approach; if successful, in later stages we will move on to baryons and investigate the internal structure of the nucleon. This also provides an opportunity for strengthening our ties with the Partons and QCD and Pheno groups.

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. A PhD student has already started to work on pentaquarks, and the prime example for a six-quark state is the deuteron, which we are planning to explore within 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 for hadron properties, which should significantly elevate the status quo in the theoretical calculation of hadron observables.

Meson spectroscopy: Our final goal is a comprehensive description of meson properties covering the light and the heavy quark sector within the Covariant Spectator Theory, starting by implementing a dynamically obtained quark mass function.

Baryon spectroscopy and structure: Based on our new calculations of the heavy-baryon spectrum, the goal is to extend these studies to also understand the spectrum and structure of hyperons, including their spacelike and timelike form factors.

Medium-term (3-5 years) prospects

Given the opportunities for growth in terms of funding and securing permanent positions, we expect to further consolidate and broaden our internationally recognized expertise in theoretical nuclear and hadron physics:

Hadron spectroscopy: Our unique expertise on functional methods especially also for 3- and 4-body systems enables us to extend our portfolio to pentaquarks and other exotic hadrons. Another important goal is to consolidate our theoretical methods towards an ab-initio approach, where a wide range of hadron properties can be calculated from first principles without any parameters.

Hadron structure: In view of the forthcoming EIC, 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 exotic 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 (although consolidation efforts are underway).

Threats

- Lack of funding threatens the group's activities.
- Lack of permanent positions creates instability and insecurity.

NPstrong

Publications

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

- *"Quark Mass Function from an OGE-type Interaction in Minkowski Space"*, E. P. Biernat, F. Gross, M. T. Peña, A. Stadler, S. Leitão, Acta Phys. Polon. Supp. 14 (2021) 9
- *"Mass generation in Landau-gauge Yang-Mills theory"*, G. Eichmann, J. M. Pawlowski, J. M. Silva, Phys. Rev. D 104 (2021) 11, 114016

Presentations

6 Oral presentations in international conferences

- Gernot Eichmann: *"Studying mass generation in Yang-Mills theory"*, 2021-03-21, Workshop "FunQCD: From first principles to effective theories", Valencia, Spain
- Gernot Eichmann: *"Exotic mesons with functional methods"*, 2021-04-22, Workshop "Mass in the Standard Model and Consequences of its Emergence", valid for ECTS credits, Trento, Italy
- Gernot Eichmann: *"Resonance studies in the Bethe-Salpeter framework"*, 2021-07-30, Hadron 2021, Mexico City, Mexico
- Gernot Eichmann: *"Studying mass generation in Landau-gauge Yang-Mills theory"*, 2021-11-02, XIII International Workshop on High-Energy Physics, Protvino, Russia
- Gernot Eichmann: *"Kaon contribution to muon g-2"*, 2021-11-04, EINN 2021, Cyprus
- Gernot Eichmann: *"Going to the light front with contour deformations"*, 2021-12-01, Light Cone 2021, South Korea

5 Oral presentations in advanced training events

- Gernot Eichmann: *"From nuclei to quarks and gluons"*, 2021-07-15, 6th Lisbon mini-School on Particle and Astroparticle Physics, Caparica
- Alfred Stadler: *"Hands-on Hadron Physics: The quarkonium spectrum"*, 2021-07-16, 6th Lisbon mini-School on Particle and Astroparticle Physics,
- Elmar Biernat: *"Hands-on Hadron Physics: Color factor in the qq^- interaction"*, 2021-07-16, 6th Lisbon mini-School on Particle and Astroparticle Physics,
- Alfred Stadler: *" Visita Guiada ao Modelo Padrão das Partículas Elementares"*, 2021-09-10, 8º Encontro de Professores de Física Química, University of Évora, Portugal
- Gernot Eichmann: *"Theory overview on baryon spectroscopy"*, 2021-10-19, 2021 School on the Physics of Baryons, Sevilla, Spain

2 Seminars

- Gernot Eichmann: *"QCD contributions to the muon anomalous magnetic moment"*, 2021-07-08, Teilchentee, University of Heidelberg
- Teresa Peña: *"Crossing the Boundaries to explore baryon resonances"*, 2021-09-16, LIP Seminar, LIP Lisboa

Organized Events

1 National Conference or Workshop

- *"8º Encontro de Professores de Física Química"*, [Conf-WS-Nat] 2021-09-09 / 2021-09-10, University of Évora, Portugal

1 Advanced Training Event

- *"2021 School on the Physics of Baryons"*, [Adv-Trng] 2021-10-18 / 2021-10-22, Seville, Spain (Online)

Theses

1 PhD

- Raúl Torres: *"Pentaquark spectroscopy for the LHC"*, 2021-04-01 , (ongoing)

3 Master

- Madalena Lourenço: *"Pentaquarks in QCD"*, 2019-11-01 / 2021-01-19, (finished)
- Eduardo Ferreira: *"From light-front wave functions to parton distribution functions"*, 2020-11-01 / 2021-11-25, (finished)
- André Torcato: *"Heavy-baryon spectroscopy in a quark-diquark approach"*, 2020-11-01 / 2022-03-11, (finished)

[Cosmic rays]

AMS

Auger

SWGO

RESEARCH / COSMIC RAYS

AMS

Collaboration in AMS - Alpha Magnetic Spectrometer

Principal Investigator:
Fernando Barão (60)

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):***
Ana Sofia Sousa, Francisco Rodrigues, Guilherme Simplício

1 ***External collaborator(s):***
Eduardo Bueno

Total FTE:
3.3

Articles in international journals:	**5** Indirect contribution
International conferences:	**2** Oral presentations
Collaboration meetings:	**2** Oral presentations
Advanced Training Events:	**2** Student presentations
Seminars:	**2** 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; a final detector was installed in the international space station (ISS), in May 2011. The experiment is expected to be carried out 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 171 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 measuring particle's velocity very precisely. In that context, the group is responsible for the development, implementation and maintenance of a set of algorithms for reconstructing the particle's electric charge and velocity with the RICH. The group was also involved in studies related to isotopic sensitivity.

Following the launch of AMS in 2011, the group got 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 data analysis to its research efforts. This led to the study of the galactic cosmic-ray flux with particular emphasis on variability studies related to solar activity. The group already contributed to the area with a few papers studying not only the correlation between the sun and the cosmic-ray flux but also the intrinsic propagation mechanisms present in solar modulation.

Recently the group got (more) involved in deuteron/proton separation and isotope flux analysis. Isotope fluxes are fundamental in understanding galactic matter distribution and cosmic-ray transport mechanisms, since isotopes can be used to probe different space depths due to their intrinsically different cross-section. The RICH subdetector is a key player in this analysis due to its measurement accuracy, since it enables mass separation capabilities beyond any other detector in space, making the 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 LPSC - Grenoble, INFN - Perugia and University of Geneva AMS research groups and, in November 2019, joined efforts with the Groningen AMS group on the topic of deuteron analysis of AMS data as Fernando Barão started supervising Eduardo Bueno, PhD student on their group.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Fernando Barão		50.000 €	2019-09-01 / 2021-11-30	CERN/FIS-PAR/0013/2019 / Collaboration in the International Space Station Experiment AMS for the detection of intermediate energy cosmic rays
Fernando Barão	Luisa Arruda	45.000 €	2021-12-01 / 2023-11-30	CERN/FIS-PAR/0007/2021 / AMS-LIP_Colaboração na experiência AMS da estação espacial internacional para deteção de raios cósmicos de energia intermédia

AMS

Overview

The main activities where the LIP AMS group is involved are the following:

1. RICH subdetector
The LIP group was 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 in 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 periodic phenomenon known as the solar activity cycle. As the solar activity cycle unfolds, the number of sunspots increases with the number of magnetic domains near the surface of the Sun, thus changing 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, known as Forbush decrease and it presents a very specific time signature.

The tilted-dipole geometry also creates a macro-structure known as the heliospheric current sheet, which separates the two polarities of the solar magnetic field and has a complex shape, since it mixes solar rotation with a variable solar wind speed and an angular offset with respect to the solar rotational axis. It plays a major role in the propagation of cosmic rays in the solar system and, since it is connected to the Sun's rotation, Earth crosses it two times about every 27 days (one solar rotation). This time-dependent process is known as solar modulation and it translates into the cosmic-ray flux as a low-energy time variability.

Solar activity, varying in a periodic way, thus affects cosmic-ray (CR) fluxes arriving at Earth, particularly up to rigidity cutoff values around 40 GV. Such variations are expected to depend on the particles charge sign. Since 2011 the LIP group is involved in the study of the solar modulation of CRs and in their 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 boosted decision trees (BDT) or PDF techniques. Such tools were applied to anti-proton/electron separation and isotope identification. Currently, the group's main focus on this topic is deuteron separation with respect to its closest most abundant species, the proton. This requires a detailed understanding of the measurements involved, state-of-the-art data analysis techniques and possibly the usage of a novel approach that includes the geomagnetic cutoff to create mass separation regions of the time varying CR velocity spectrum.

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 activities, performing shifts and acting as on-call experts for the RICH detector.

Assessment of the past year: objectives vs. achievements

Variability studies of AMS fluxes at low energy

Cosmic ray fluxes were calculated using an analysis framework developed by the LIP group and is significantly sped up by using reduced data produced by another member of the collaboration (Laurent Derome, researcher at LPSC in Grenoble), in collaboration with our group.

The selection algorithm for protons was finished and we worked towards efficiency estimation and regularization in order to accurately describe detector effect, using a tool developed by the group. Despite encountering several difficulties related to disk storage space, this analysis effort amounted in a extension of the proton flux up to March of 2019.

The group continued its work on the development of a Bayesian unfolding algorithm (this effort was led by FB) which, in a data-driven manner, unfolds a flux based only on the migration matrix and on the efficiency-corrected rates measured by the AMS detector. This algorithm will allow for the fluxes to be unfolded in parallel and independently.

The AMS proton flux is being interpreted under the Force-Field model and both the 1D finite-difference and 2D stochastic numerical solutions of Parker's Transport Equation, with the goal of relating solar observables to direct proton flux observation. The work is still undergoing and will expand upon a previous result from the group on the delay between solar observables and the cosmic-ray flux.

The group also started developing a wavelet framework which will be used to analyse the AMS cosmic-ray flux and solar observables. The major periodic components need not only to be determined accurately but also to be compared to the underlying red-noise background processes.

Keeping up with its usual participation in the LIP Summer Student Programme, the group tutored a student on the wavelet analysis topic and produced some preliminary results on time series of solar sunspot numbers from several observatories.

Light isotope nuclei identification

Selection of deuterons is intrinsically a difficult task given their very low abundance with respect to the major proton component. Separation of the different mass particles can be achieved by selecting velocity and looking into the momentum spectrum, as long as momentum resolution allows. A more "natural" way of addressing

this problem is to look into the derived mass spectrum, turning the focus to the construction of reference distributions for fitting the full mass spectrum. These mass templates are built from MC simulations, requiring the study of detector resolution and systematic biases of MC samples with respect to data in order to evaluate corrections to be applied. Factors such as flux spectral shape and the geomagnetic cutoff are taken into account. This work is still ongoing.

The AMS RICH detector is able to measure particle velocity with a resolution factor ten times that of the AMS TOF. However, for singly charged particles, there is a low number of hits near the measurement threshold (specially for NaF) making velocity reconstruction specially sensitive to noisy hits, thus biasing velocities towards lower values and, consequently, higher masses, which is a limiting factor for deuteron identification. Proton/deuteron selection criteria has to be developed having these aspects in mind, opening a door to modern machine learning methods combining different detectors.

This analysis is being done in collaboration with the Groningen University AMS group, already resulting in presentations in international conferences (such as ICRC 2021) and several collaboration analysis meetings and reports, advancing AMS's contributions in the field of astroparticle physics. In the context of collaborating with the Geneva AMS group, the group worked very closely with Jiahui Wei on the berillium flux estimation, resulting in the defense of his PhD thesis in which Fernando Barão was a member of the jury.

POCC Shifts, RICH performance and Heavy nuclei identification

RICH detector is a central detector used in isotopic flux analysis made by the different groups in AMS, by providing velocity measurements with great accuracy. In addition, data selections used in flux estimation use the coherence of the velocity measurement made by the two RICH algorithms existing in AMS, one of which was developed by the LIP group.

RICH's capability of measuring particle charge is also used as a complement to other detector charge measurements made along the detector. RICH charge reconstruction algorithms co-developed by LIP aid in the study of heavier nuclei when determining fragmentation of cosmic rays inside of the detector.

LIP team members have been participating in AMS mission control activities, performing RICH, TOF and ECAL shifts and acting as on-call experts for the RICH subdetector. Due to the COVID-19 outbreak and its associated travel restrictions, no shits were attended by any of AMS' collaborators except for members permanently hosted at CERN.

Lines of work and objectives for next year

Solar activity and modulation of CR fluxes

Since its launch, AMS has monitored the cosmic-ray 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 has begun the development of a wavelet analysis tool in order to study these time series and their complex frequency spectra as a function of time and rigidity.

The AMS/LIP group developed algorithms to numerically solve the transport equation of CRs in the solar system in several scenarios and approximations. These studies provide a great foothold for the phenomenological study of solar modulation. The group intends to use this framework to further study the connection between the solar activity cycle (and the variation of solar observables) with the variations in the CR fluxes measured both by AMS and neutron monitors at ground level. The study of these observables with the fluxes of differently charged particles (including isotopes and antiparticles) allows probing different aspects of the transport mechanism.

Selection of nuclei and isotopes using high precision selection algorithms

The analysis of deuterons and their separation from protons up to a kinetic energy per nucleon of 10 GeV is ongoing, remaining a hard task given the percent fraction of secondary deuterons abundance. A good rejection of biased reconstructed and fragmented events in the detector is crucial to extend as much as possible their energy analysis range. Even though deuterons are primarily produced in stars via proton-proton chain, CR deuterons are mostly of secondary origin and are produced by interactions of p, He-3, He-4 with the inter-stellar medium (ISM).

The group is strongly involved in this analysis and will contribute to the development of statistical mass estimators, that will be used as template distributions on deuteron-proton separation. Helium events can fragment in the AMS experiment and contribute to the detected deuterons. Its contribution has to be studied and included as a template contribution to the event mass distribution. In addition, the group is developing a Bayesian unfolding method to be applied to the measured fluxes requiring regularized distributions reproducing the measured variables migration effects. The outcome of the analysis will be the measurement of deuteron fluxes in terms of kinetic energy per nucleon and rigidity. A deep understanding of all contributing errors of statistical and systematic nature is needed and will be worked out.

Mass templates are a key issue in isotope separation and require a good fine tuning of the MC detector simulation with respect to data. While this method gives good results, a cross-check from independently data derived mass templates can be a plus. Such data-driven mass templates will be extracted from data mass distributions assuming a nearly independent mass resolution and using linear transformations.

The AMS/LIP group will continue these works and the exploration of state-of-the-art selection techniques such as the geomagnetic cutoff method or multivariate analysis (multi-layer perceptrons, boosted decision trees, template fitting, etc.) to explore other light isotopes. One of the by-products of this work will be to supply the resulting fluxes and ratios as additional tools to study solar modulation. This is a very attractive topic to pursue both scientifically and with respect to AMS' analysis efforts.

Medium-term (3-5 years) prospects

AMS observed the 24th solar activity cycle almost from beginning to end, through the reversal of the solar magnetic dipole in 2013, and will continue operating at least until the magnetic reversal of the current cycle (25th) in 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 footstep on both interpretation and modelling, and extending to isotope fluxes, which will enable probing different aspects of diffusion by taking advantage of the shift in velocity for the same charge.

Using frequency-spectrum and wavelet analysis, temporal structures in CR data can be correlated to solar parameters in order to better understand solar wind and the diffusive propagation of CRs in it. Combining this knowledge with CR transport simulation tools, diffusion models can be tested and parametrized through direct comparison with experimental data.

The group will also keep researching isotopic separation profiting from our experience with both the RICH detector and data-driven likelihood models applied to particle separation. This topic is also of particular interest to astrophysical and Dark Matter studies since it greatly contributes to better understanding the propagation mechanism of CRs in the galaxy. It also constitutes a good opportunity to explore new mass template techniques: geomagnetic cutoff or iterative data-driven processes.

SWOT Analysis

Strengths

Experienced team in experimental, astroparticle and computational physics, with extensive computational and data science skills
Long history of close collaborations with international 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 this group and other LIP research groups.

Opportunities

AMS remains a unique observatory in space.
Increased interest by 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

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

- *"Properties of Iron Primary Cosmic Rays: Results from the Alpha Magnetic Spectrometer"*, AMS Collaboration, Phys.Rev.Lett. 126 (2021) 4, 041104
- *"The Alpha Magnetic Spectrometer (AMS) on the international space station: Part II — Results from the first seven years"*, AMS Collaboration, Phys.Rept. 894 (2021) 1-116
- *"Properties of Heavy Secondary Fluorine Cosmic Rays: Results from the Alpha Magnetic Spectrometer"*, AMS Collaboration, Phys.Rev.Lett. 126 (2021) 8, 081102
- *"Properties of a New Group of Cosmic Nuclei: Results from the Alpha Magnetic Spectrometer on Sodium, Aluminum, and Nitrogen"*, AMS Collaboration, Phys.Rev.Lett. 127 (2021) 2, 02101
- *"Periodicities in the Daily Proton Fluxes from 2011 to 2019 Measured by the Alpha Magnetic Spectrometer on the International Space Station from 1 to 100 GV"*, AMS Collaboration, Phys.Rev.Lett. 127 (2021) 27, 271102

Presentations

2 Oral presentations in international conferences

- E. Bueno, F. Barão, M. Vecchi: *"Measurement of the deuteron flux in cosmic rays with the AMS-02 experiment"*, 2021-01-20, Physics@Veldhoven 2021, Online
- E. Bueno, F. Barão, J. Berdugo, C. Delgado, F. Dimiccoli, D. Coral, M. Vecchi, P. Zuccon, P. Doetinchem, for the AMS Collaboration: *"Precision Measurement of Cosmic-Ray Deuterons with the Alpha Magnetic Spectrometer"*, 2021-07-19, ICRC 2021, 37th International Cosmic Ray Conference – The Astroparticle Conference, Berlin, Germany

2 Student presentations in advanced training events

- Guilherme Simplício, Miguel Orcinha, Fernando Barão: *"Time variability of Cosmic Rays"*, 2021-09-13, LIP Internship Program 2021, Lisboa, Portugal
- Ana Sofia Sousa, Francisco Rodrigues, Fernando Barão: *"LabRC: Muon Telescope Acquisition"*, 2021-09-13, LIP Internship Program 2021, Lisboa, Portugal

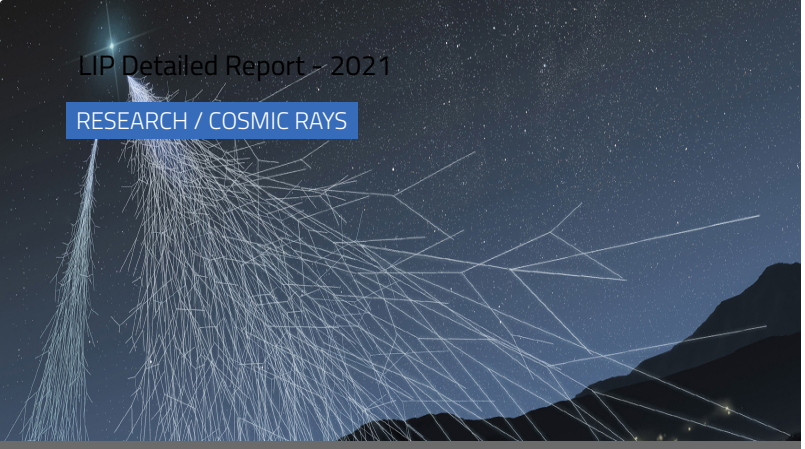
2 Outreach seminars

- Luisa Arruda: *"Espaço: Para o infinito e mais além mas em segurança!"*, 2021-10-27, O Espaço vai à Escola- ESERO, Colégio Valsassina Lisboa
- Luisa Arruda: *"Espaço: Para o infinito e mais além mas em segurança!"*, 2021-11-04, O Espaço vai à Escola- ESERO, Externato Champagnat (virtual)

Theses

1 PhD

- Miguel Orcinha: *"Estudo da modulação Solar no fluxo de raios cósmicos com dados da experiência AMS"*, 2015-03-30 , (ongoing)



AUGER

Collaboration in the Pierre Auger Observatory

Principal Investigator:
Pedro Assis (76)

12 ***Researcher(s):***
Alessandro de Angelis (11), Bernardo Tomé (61), Catarina Espírito Santo (15), Felix Riehn (100), Liliana Apolinário (15), Lorenzo Cazon (71), Mário Pimenta (40), Patrícia Gonçalves (20), Pedro Abreu (74), Raul Sarmento (90), Ruben Conceição (55), Sofia Andringa (19)

4 ***Technician(s):***
José Carlos Nogueira (73), Luís Lopes (26), Luís Mendes (75), Miguel Ferreira (72)

2 ***PhD Student(s):***
Luís Afonso (16), Pedro Teixeira (83)

4 ***Master Student(s):***
Alexandra Fernandes (95), Beatriz Artur (25), Miguel Martins (89), Milton Freitas (31)

12 ***Undergraduated Student(s) and Trainee(s):***
Diogo Costa, Diogo Ventura, Inês Brioso Dias, Isabel Alexandre, João Gomes, Margarida Baptista, Miguel Godinho, Pedro Mendes, Raquel Nunes, Ricardo Correia, Rodrigo Pereira

1 ***Additional LIP collaborator(s):***
Magda Duarte

3 ***External collaborator(s):***
Gonzalo Parente, João Espadanal, Ricardo Luz

Total FTE:
12.4

Articles in international journals:	**3** Direct contribution **6** Indirect contribution
Notes:	**5** LIP Students notes
Nat.& Internat. meetings:	**1** Oral presentation
Collaboration meetings:	**4** Oral presentations
Advanced Training Events:	**1** Oral presentation **6** Student presentations
Seminars:	**2** Seminars
Completed theses:	**2** MScs

Executive summary

The Pierre Auger Observatory, the largest cosmic ray detector, has brought new fundamental insights into the origin and nature of the highest-energy cosmic rays while raising further questions about their nature, origin, and the physics governing interactions at the highest energies. The Collaboration is performing an upgrade expected to increase the data quality.

One of the most exciting results is the experimental proof that the cosmic-ray flux is strongly suppressed at the highest energies (~10^{20} eV). However, the mechanism responsible for such suppression is still a subject of debate between a cosmic scenario where sources exhaust and the GZK scenario where the energy of individual cosmic rays is degraded by their interaction with cosmic microwave background (CMB) photons in their voyage to Earth. Extensive Air Shower (EAS) parameters sensitive to the primary cosmic ray mass seem to favour a heavy composition scenario whereas the existence of anisotropies favours a light primary scenario. However, the physics of the interactions of the Ultra-High Energy Cosmic Rays (UHECR) with Earth's atmosphere is not tested by human-made accelerators, resulting in a large uncertainty in EAS' description, which thus hampers the comprehension of the whole UHECR picture.

The Auger full detector upgrade, consisting of installing scintillators on top of the existing water Cherenkov detectors and the upgrade to faster electronics, aims to provide a better knowledge of the different components of EAS. A great effort is being made in the next-generation analysis and in the development of phenomenological models to attain a good description of the Air Shower observables. The muonic component plays a significant role in probing the hadronic component of the shower directly in the early stages. Muons are indirectly accessible with the new upgrade, with refined analysis to separate them from the dominant electromagnetic signals. A small part of the array will be equipped with extra detectors to understand and calibrate the full array measurements at lower energy.

The LIP team has been deeply involved in the last years in developing the MARTA project, a joint Portugal-Brazil effort to directly measure the muon content at the shower front using RPC detectors installed beneath the water Cherenkov detectors. Low gas flux RPCs developed at LIP-Coimbra were built in cooperation with Brazilian institutes, and its first data was foreseen for 2020. Prototypes have been working regularly at Malargüe. MARTA detectors will be used to understand the Auger surface detectors, for the validation and test in situ of the scintillation detectors and detailed shower studies at lower energies (10^{17} eV, interactions closer to the LHC centre-of-mass energies).

The LIP team has strong competencies in air shower physics and is co-coordinating the efforts in this field. The team has contributed to several analyses and is focused on the relation between the first few interactions, taking place at the highest energies, and the observables at the ground, affecting shower development. One such observable is the muon content, and the group is establishing a direct relationship between its content and the pion production properties. Efforts will continue to measure the pion production at the highest energies.

Part of the activities of the group were severely impacted by the pandemic. The travel restrictions made it impossible to finish the detectors' commissioning and imposed strict confinement in Argentina, which substantially impacted fieldwork even by the Observatory staff. However, work continued where possible in laboratory activity and on the development of software and preparation of analyses.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Pedro Assis	Lorenzo Cazon	135.000 €	2019-09-01 / 2021-08-31	CERN/FIS-PAR/0034/2019 / Enhancement of the measurement capabilities of the Pierre Auger Observatory
Lorenzo Cazon	Ruben Conceição	75.000 €	2019-09-01 / 2021-09-30	CERN/FIS-PAR/0031/2019 / UHECR Physics with the Pierre Auger Observatory
Pedro Assis	Ruben Conceição	135.000 €	2021-09-01 / 2023-08-31	CERN/FIS-PAR/0012/2021 / AugerEnhance_Aprimoramento das capacidades de medição do Observatório Pierre Auger
Ruben Conceição	Pedro Assis	70.000 €	2021-10-01 / 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 and development of the detectors to improve the data quality and the data analysis and model development. Several significant results have been achieved.

The group is mainly involved in the full exploitation of the Observatory particle physics potential, namely in the efforts to understand hadronic interactions at high energies through a window that is largely complementary to the LHC. The group is very focused on understanding the relationship of the properties of the very first interactions with the observable muon content on the EAS development.

On the detector development side, the group has strong competences in GEANT4 simulation and RPC development. Moreover, it has facilities for RPC development and production and a fast-electronics laboratory. The group is leading the MARTA project to enhance muon detection capabilities.

Assessment of the past year: objectives vs. achievements

The COVID-19 pandemic has been more limiting than expected in 2021. It remained impossible to travel to Argentina for fieldwork. Also in Brazil, our partner in the final assembly of the RPCs, activities have been severely limited by the restriction imposed by the pandemic.

The most significant impact was still on the commissioning of the first MARTA station. The installed hardware needs to be recabled, and the Central Unit interface updated, which has proven impossible to do. Solutions were found in the laboratory and we are waiting for the possibility of a mission to Argentina for fieldwork.

It was planned to upgrade and install hodoscopes to test the response of the Auger tank to muons and to test and cross-calibrate the novel detectors to be installed at the Auger array. This was also not possible to achieve as it requires upgrades of the hardware and fieldwork.

The simulation and software framework has been concluded. This is now a part of the official Auger Software and is being maintained by members of the LIP group.

The study of EAS continued, and work was centred on the capability to estimate the properties of the pion energy distribution from the measurement of the tail of the muon distribution at ground level. The ability to perform this difficult but very promising measurement with the MARTA engineering array has started to be investigated using dedicated end-to-end simulations.

The Auger Collaboration has publicly released about 10 % of the collected data, together with analyses tools. Several activities were organized in this context. Data have also been used for assignments in several courses in the Physics Master programme at IST. Moreover, Auger Masterclasses are being prepared and will take place soon.

The outreach at Mina do Lousal has also been pursued, and the connection with the local Ciência Viva centre and museum has been reinforced. A novel detector is being prepared for muon tomography, and an interactive module for the museum is being developed.

Lines of work and objectives for next year

The group pursues an ambitious program funded by two projects approved in 2021 and organized in the following tasks:

AugerEnhance: Enhancement of the measurement capabilities of the Pierre Auger Observatory:

- MARTA commissioning and monitoring
- Detector & Electronics R&D
- MARTA simulation and data analysis
- Auger Detector Performance & Calibration
- Outreach

UHECR@Auger: UHECR Physics with the Pierre Auger Observatory

- Shower Physics & Hadronic Interaction Models
- Shower & Muon reconstruction
- Implications for Mass & Global UHECR Interpretation
- Cosmic Rays for Education and Society

In the end of 2020 L. Cazon was nominated as Science Coordinator and R. Conceição assumed the chair of the Air Shower Physics task.

The main activities will be two-fold in the next year:

- Commission the MARTA detectors.
- Pursue EAS characterisation studies and assess the present and future detector capabilities.

The pandemic has proven to be longer and more restricting than expected. At present, it is expected to be able to travel to Argentina in Q2-Q3. Work in the laboratory has been developed to prepare the commissioning of MARTA stations that is expected to occur in 2022. The main focus will be on the first complete MARTA station and the support systems like test hodoscopes.

The MARTA simulation framework is now developed, installed and maintained as part of the Auger official software framework. We plan to exploit this tool with an extensive simulation plan to prepare for data taking. Namely, we will prepare the analysis tools for MARTA and study its performance. We expect to attract students to develop master theses and hopefully continue for PhD.

The mass determination of UHECR and the potential for charged particle astronomy is currently limited by the uncertainties in the description of hadronic interactions. These occur in phase-space and energy regions beyond the reach of human-made accelerators and present challenges and opportunities. Its study can even give input to steer developments in future colliders. Studies will be centred on the muon component of EAS. After the measurement of the muon number distribution fluctuations, led by the LIP group, the focus will be on muon profile shape and energy spectrum. These studies will be conducted bearing in mind the novel detectors becoming online, which will give further information on the muon spectra.

The group also has an ambitious outreach programme whose aims are two-fold:

- Bring the data and results produced by the Pierre Auger Observatory to a wider community and contribute for the use for different purposes and by different groups.
- Communicate particle and cosmic ray science to the public employing the detectors and techniques developed at LIP.

Medium-term (3-5 years) prospects

Understanding the nature of cosmic rays and particle interactions at the highest energies is paramount to further advance knowledge in this field. The Pierre Auger Observatory is currently the best experiment to perform such studies. LIP is well integrated in the Collaboration, where it has clear and strong responsibilities in detectors, analyses and phenomenology studes. LIP group members have responsibilities in task coordination and have served in committees and management bodies of the collaboration.

In the next years, the MARTA engineering array will be installed in a region of Auger dedicated to lower energy cosmic rays, thus providing high statistics despite its modest size. It will be operated in coincidence with the standard Auger detectors, the upgrade's scintillator and the AMIGA detector (installed a couple of meters below ground). Cross-calibration and study of the observatory performance using all the detectors is of paramount importance for the Observatory. The LIP group will be engaged in this task taking a pivotal role.

Taking advantage of its expertise in EAS muon measurement, analysis and modelling, the group will continue the studies in the hadronic sector of EAS, probing interactions at the highest energies, and studying in detail the muonic cascade and its relation to the nature of the primary and the early, high-energy interactions. For a limited sample of events, MARTA will provide a clean measurement of the muon content and time structure. Moreover, MARTA will probe the energy region where there is an overlap with the LHC and where hadronic interaction models start to fail predictions on the number of muons. Hence, the exploration of the muon EAS content at MARTA is in a privileged position to finally solve the so-called muon problem in cosmic rays. AugerPrime, with its upgraded capabilities, will allow not only to improve our understanding of EAS but also the response of the different detectors. New analyses will come into play, which can be used to reprocess previously collected data and increase the exposure once validated. Moreover, understanding the muon and electromagnetic component relation will boost the knowledge of the nature of primary cosmic rays and allow for a boost in multi-messenger astrophysics.

SWOT Analysis

Strengths

The LIP team is relatively large, both in the number members and competences. While the bulk of the team is in Lisbon, it relies on a close collaboration between the three LIP nodes, with the involvement of the Coimbra RPC team and the Minho analysis team.

The FCT commitment with the Portuguese participation in the Pierre Auger Observatory, valid until 2025, and the recent approval of funding for the group provides a stable framework.

MARTA detectors have proved their capabilities to run in harsh environments, showing that RPCs are suitable for cosmic ray applications. Most of the necessary pieces for the deployment of the Engineering Array are produced.

The group has a strong competence in high-energy cosmic ray phenomenology, namely in muon analyses, modelling, and hadronic interactions.

Weakness

The team has a rather small number of master and PhD students, leading to a lack of workforce for some of the existing tasks and the development of new work lines. The group's funding level is low for the number of team members and the responsibilities within the Collaboration, namely the MARTA project. Resource are limited, thus missions for meetings and fieldwork in Latin America must be wisely chosen.

Opportunities

The group will be in a privileged position for performing detailed and precise measurements of the muon component with the MARTA engineering array.

Visibility within the university is increasing, and this is an opportunity to attract new students. Lecturing in the Master in Physics program at IST and participation in thematic schools is increasing the awareness of this field. The LIP Remote Control Room at Técnico and the LIP Internship Programme also give a significantly contribution. R&D opportunities or potential RPC applications in future astroparticle physics projects should be pursued, with a great synergy with the SWGO group and the Muon Tomography Project.

Threats

The group must attract new students for its diversified activities. Lack of funding for PhD students is also a threat to the development of the group activities.

Auger

Publications

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

- *"Constraining the energy spectrum of neutral pions in ultra-high-energy proton-air interactions"*, Lorenzo Cazon, Ruben Conceição, Miguel Alexandre Martins, and Felix Riehn, Phys. Rev. D 103, 022001
- *"Measurement of the Fluctuations in the Number of Muons in Extensive Air Showers with the Pierre Auger Observatory"*, Pierre Auger Collaboration (360 authors), Phys. Rev. Lett. 126 (2021) 152002
- *"Extraction of the muon signals recorded with the surface detector of the Pierre Auger Observatory using recurrent neural networks"*, Pierre Auger Collaboration (372 authors), J. Instrum. 16 (2021) P07016

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

- *"Design, upgrade and characterization of the silicon photomultiplier front-end for the AMIGA detector at the Pierre Auger Observatory"*, Pierre Auger Collaboration (352 authors), J. Instrum. 16 (2021) P01026
- *"Calibration of the underground muon detector of the Pierre Auger Observatory"*, Pierre Auger Collaboration (364 authors), J. Instrum. 16 (2021) P04003
- *"The FRAM robotic telescope for atmospheric monitoring at the Pierre Auger Observatory"*, Pierre Auger Collaboration (372 authors), J. Instrum. 16 (2021) P06027
- *"Design and implementation of the AMIGA embedded system or data acquisition"*, Pierre Auger Collaboration (383 authors), J. Instrum. 16 (2021) T07008
- *"Deep-learning based reconstruction of the shower maximum X(max)( )using the water-Cherenkov detectors of the Pierre Auger Observatory"*, Pierre Auger Collaboration (372 authors), J. Instrum. 16 (2021) P07019
- *"The energy spectrum of cosmic rays beyond the turn-down around 10(17) eV as measured with the surface detector of the Pierre Auger Observatory"*, Pierre Auger Collaboration (376 authors), Eur. Phys. J. C 81 (2021) 966

5 LIP Students Notes

- *"Search for High Energy Astrophysical Multimessengers"*, João Gomes, Margarida Baptista and Miguel Godinho, LIP-STUDENTS-21-13
- *"Muography Optimization"*, M. Inês Dias and Rodrigo Pereira , LIP-STUDENTS-21-17
- *"Development of an interface to analyze events at the Pierre Auger Observatory, for use in Masterclasses"*, Ricardo Correia, LIP-STUDENTS-21-20
- *"Muography: Simulation of Muon Telescope Sensitivity"*, Isabel Alexandre, LIP-STUDENTS-21-29
- *"Pierre Auger vs. The Machine: towards validation of deep-learning based reconstruction of ultra-high energy cosmic rays with new data from the Pierre Auger Observatory"*, Diogo Costa, LIP-STUDENTS-21-32

Presentations

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

- Felix Riehn: *"Hadronic event generator Sibyll"*, 2021-11-26, 3rd Forward Physics Facility Meeting (CERN), Online

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

- R. Conceição: *"Observatório Pierre Auger e SWGO: Duas janelas para o Universo extremo"*, 2021-11-06, Escola Avançada de Professores em Língua Portuguesa, CERN (Online)

6 Student presentations in advanced training events

- Raquel Nunes (supervisors R. Conceição, F. Riehn, L. Cazon): *"Investigation of the muon puzzle at the Pierre Auger Observatory"*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online
- Diogo Costa (Supervisors : F. Riehn, R. Conceição, L. Cazon): *"Pierre Auger vs. The Machine: towards validation of deep-learning based reconstruction of ultra-high energy cosmic rays with new data from the Pierre Auger Observatory"*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online
- Ricardo da Silva Correia (supervisors R. Sarmento, H. Carvalho): *"Desenvolvimento de uma interface para analisar eventos do Observatório Pierre Auger, para uso em Masterclasses"*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online
- Isabel Alexandre (supervisors : P. Teixeira, R. Sarmento, S. Andringa): *" Muography: Simulation of Muon Telescope Sensitivity"*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online
- Inês Dias, Rodrigo Pereira (supervisors : R. Sarmento, S. Andringa): *"Optimização da muografia "*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online
- João Gomes, Margarida Baptista, Miguel Godinho (supervisor : R. Sarmento): *"Search for High Energy Astrophysical Multi-Messengers "*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online

2 Seminars

- Felix Riehn: *"News on the muon puzzle! Pierre Auger Observatory measures muon fluctuations."*, 2021-03-18, LIP Seminar, Online
- Felix Riehn: *"Hadronic interactions at ultra-high energy"*, 2021-07-01, RAPP Center Seminar series (TU Dortmund), Online

Theses

2 PhD

- Pedro Teixeira: *"Tomografia de Muões com RPCs na Mina do Lousal"*, 2017-09-25 , (ongoing)
- Luís Afonso: *"Raios Cósmicos: desenvolvimento de módulos de divulgação através design participativo"*, 2021-11-23 , (ongoing)

4 Master

- Alexandra Fernandes: *"Study of Fast Radio Bursts (FRBs) and multimessenger astrophysics with the Pierre Auger Observatory"*, 2020-09-18 / 2021-11-26, (finished)
- Miguel Martins: *"Measurement of the features of muon number distribution using MARTA engineering array"*, 2020-11-01 / 2021-11-26, (finished)
- Beatriz Artur: *"evaluation of the existence of QGP in air showers"*, 2021-10-01 , (ongoing)
- Milton Freitas: *"Measurement of the number of muons in high occupancy MARTA stations"*, 2021-10-06 , (ongoing)

SWGO

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

Principal Investigator:
Mário Pimenta (46)

10 ***Researcher(s):***
Alberto Blanco (6), Alessandro de Angelis (24), Bernardo Tomé (38), Catarina Espírito Santo (30), Fernando Barão (15), Giovanni La Mura (100), Paulo Fonte (15), Pedro Abreu (31), Pedro Assis (14), Ruben Conceição (37)

4 ***Technician(s):***
José Carlos Nogueira (16), Luís Lopes (15), Luís Mendes (31), Miguel Ferreira (18)

2 ***PhD Student(s):***
Borja González (75), Lucio Gibilisco (29)

2 ***Master Student(s):***
Laura Peres (100), Pedro Costa (100)

3 ***Undergraduated Student(s) and Trainee(s):***
Bernardo Martins, Matilde Carapuça, Tatiana Mendes

5 ***External collaborator(s):***
Adriano Henriques, Alberto Guillén, Luis Filipe Mendes, Pedro Brogueira, Ricardo Luz

Total FTE:
7.4

Articles in international journals:	**5** Direct contribution
Notes:	**3** Internal notes **1** LIP Students note
Proposals:	**1** Proposal(s) and related studies
International conferences:	**3** Oral presentations **2** Posters **4** Proceedings
Collaboration meetings:	**11** Oral presentations
Advanced Training Events:	**1** Oral presentation **1** Student presentation
Seminars:	**3** Seminars
Completed theses:	**2** MScs

Executive summary

The observations of gamma-ray telescopes in the last decade 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 open definitively a new era.

The Southern Wide-Field Gamma-ray Observatory (SWGO) was created in May 2019 in Lisbon. Today, 12 countries are oficial members of the Collaboration, which gathers over 100 scientists from 22 nations. Its goal is to design and prototype a gamma-ray detector to be installed in South America, able to monitor the Southern gamma-ray sky and 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).

Such an 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 and thus SWGO would be the only wide-field gamma-ray observatory surveying the Southern sky. It would also able to issue pointing alerts to imaging atmospheric Cherenkov telescopes (IACTs), namely to the future Cherenkov Telescope Array (CTA).

The collaboration has the ambitious plan to produce until the end of 2023 a complete proposal, including the physics goal, location, observatory layout and detector design, as well as its cost. The work of the LIP/SWGO group aims at ensuring the Portuguese participation in the endeavour. The Portuguese participation in SWGO, following the work originally developed within the LATTES framework, is focused on specific scientific goals spanning different areas: definition of the science requirements, detector design, development of analysis methods, design of innovative calibration systems.

The main topics developed in 2021 were: assessment of SWGO's capability for transients at low energies (sub-TeV); development of the concept of a small Water Cherenkov detector (WCD) where the light collection is performed by a small number of PMTs placed at the bottom, which lead to the proposal of the so-called Mercedes WCD; development of machine learning based algorithms to discriminate gamma- from hadron-induced showers at energies up to 10 TeV; the development of strategies to optimize the observatory layout in the higher energies (up to 1 PeV), including the development of a fast simulation tool.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Mário Pimenta	Ruben Conceição	239.885 €	2018-05-15 / 2021-05-14	PTDC/FIS-PAR/29158/2017 e POCI/01-0145-FEDER-029158 / LATTES: an innovative detector for very high energy gamma ray astrophysics in the southern hemisphere
Mário Pimenta	Ruben Conceição	249.585 €	2021-05-15 / 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 Southern Wide-field Gamma-ray Observatory (SWGO) Collaboration is to build the next-generation wide field-of-view gamma-ray observatory to be installed in South America. The collaboration has the ambitious plan to produce until the end of 2023 a complete proposal, including the physics goal, location, observatory layout and detector design, as well as its cost. The LIP/SWGO- group ensures the Portuguese participation in this ambitious project.

The Collaboration is organised in five Working Groups: WG1) Site; WG2) Science; WG3) Simulations and Analysis; WG4) Detectors; WG5) Communication and Outreach. LIP is actively participating in all the WGs, in each of them focusing on specific a well-defined goals. This involves contributing to the definition of the science requirements, detector design, development of analysis methods and design of calibration systems.

The SWGO management body is the Steering Committee, with representatives from each of the participating countries. M. Pimenta is the Portuguese representative in the Steering Committee; R. Conceição is co-coordinator of WG3) Simulations and Analysis; L. Mendes is responsible for the logistics evaluation subtask of WG1) Site.

Assessment of the past year: objectives vs. achievements

The work of the LIP/SWGO group is organized in the following tasks:

Task 1 - Detector R&D and Site

In 2021, the LIP group proposed a novel station concept of a small single layer water Cherenkov detector with three photomultiplier tubes (PMT) placed on its bottom, in a 120º star configuration - the Mercedes WCD. To illustrate the engineering viability of this concept, and to be able to obtain a sound first-order estimate of its cost, an engineering design was developed in collaboration with the company Rotoplastyc, from Rio Grande do Sul, Brazil. This company is highly experienced in WCDs, as it was in charge of the production and follow-up in the field of a large fraction of the Auger tanks. At the same time, in close collaboration with CBPF, a rotomolded prototype was acquired and installed.

A detailed thermal simulation of the Mercedes tank was created, using a professional code, ANSYS Fluent. This model includes fluid dynamics of the water and of the air inside the tank, ray tracing to compute the solar gains. Afterwards, simplifications to decrease the simulation time, while reproducing the physics of the system, were implemented.

LIP has also participated on the elaboration of a site characteristics matrix to ease the comparisons between the different sites.

Task 2 - Simulation and Analysis

The group was strongly committed to the development of the SWGO simulation framework and reconstruction tools. The SWGO simulation has been compared with the LATTESsim code results, in order to perform a validation of the simulation parameters.

The Mercedes station was implemented and an interface to take advantage of machine learning tools was developed. A plan to define the candidate configuration, known as milestone 5, has been developed and is currently being simulated.

A graded array layout solution for SWGO, to be implemented by phases, each one with clear physics goals has been studied.
To assess the highest energies, a fast simulation tool has been developed.

A machine learning based analysis for the discrimination of muons using small-WCDs with several PMTs has been developed and published.

Task 3 - Phenomenology

The studies on the ability to detect transient phenomena in SWGO have been pursued giving origin to two peer-reviewed publications.

An evaluation of the ability of SWGO to measure neutrino induced shower events has been initiated.

An algorithm to improve the shower energy reconstruction in gamma-ray experiments has been successfully developed and published.

The neutrino and energy reconstruction studies led to two master theses.

Task 4 - Outreach

The group developed a SWGO event viewer for outreach purposes. The tool takes advantage of the Unity graphical engine to make it more appealing to the public. It can be seen here: http://wminho.lip.pt/swgo/.

Lines of work and objectives for next year

In 2022, work will proceed with the same four tasks, with the following goals:

Task 1 - Detector R&D and site

Following the Auger specifications, work with the Brasilian companies to produce a liner able to cope with the SWGO requirements; Use the rotomolded prototype tank installed at CBPF to design the light collection system and test the liners; Study the viability of having the PMTs outside the water volume.

Finalize the thermal simulation studies producing a flexible tool to optimize an isolation layer able to avoid water freezing.

Test at the LIP-Coimbra workshop, the four RPC chambers with 2 gaps with different widths. These chambers, which have been already produced, will be tested in a hypobaric chamber to mimic high-altitude operations.

Continue the work to collect detailed information about the candidate sites for SWGO.

Task 2 - Simulation and analysis

Continue the development of the general SWGO simulation framework, prioritizing the adaption of the reconstruction algorithms to cope with all the detector concepts being evaluated. Coordination of the simulation effort to test different detector concepts and array layouts.

Validation of the fast simulation to evaluate the performance of SWGO at the highest energies (> 100 TeV), for different array layout configurations.

Task 3 - Phenomenology

The study on the feasibility to measure Gamma-Ray Bursts with SWGO will be extended to include Active Galactic Nuclei (AGN) flares. This study will be done in the context of the multi-messenger approaches, particularly the simultaneous detection of gamma and neutrino events, to understand the possible contributions of SWGO on these global searches.

The studies on the ability to measure astrophysical neutrinos with SWGO will be concluded and published.

Development of novel gamma/hadron discriminators at the highest energies (> 100 TeV). In particular, studies for a new observable based on the azimuthal signal correlations at the ground will be finalised and sent for publication.

Start studies on the identification of cosmic ray primaries with SWGO using Machine Learning techniques.

Task 4 - Outreach

The SWGO visualizer will continue to be developed to include different array configurations. This visualizer will be included in masterclasses activities, if the COVID-19 pandemic situation allows for these events.

Medium-term (3-5 years) prospects

The main goal of the SWGO collaboration is to pave the road towards the construction of the next wide field-of-view gamma-ray observatory to be installed in South America. The collaboration has an ambitious plan to produce until the end of 2023 a complete proposal, including the physics goal, location, observatory layout and detector design, as well as its cost. LIP's activities will provide essential elements for this proposal. LIP is actively engaged in activities that allow SWGO to extend the observatory energy range from 100 GeV to tens of PeV. LIP contributes to the design of the detector concept and of the array layout, simulation framework, performance benchmarking and next-generation data analysis based on machine learning techniques. LIP is also developing new detectors (RPCs) which could be used to better control the experimental uncertainties and enable more sophisticated analyses. Hence, the LIP group activities are expected to have a significant impact on the collaboration.

The activities developed are financially supported by a 3-year project FCT/PTDC ensuring the regular operation of the LIP group during the entire SWGO R&D phase.

SWOT Analysis

Strengths

Sound expertise and rich activity in cosmic-ray research, detector R&D, data analysis, simulation, air shower physics and phenomenology. World-recognised expertise in RPC development. Close links with Brazilian, Czech, Italian and Spanish groups. Funding for the entire period of the SWGO R&D phase.

Weakness

The group leads several crucial activities in SWGO and therefore there is a need to increase the human resources. The group has been steadily growing but it is still below the desired mark.

Opportunities

Extended energy range (100 GeV - 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 many different engineering and physics domains in the design, construction, operation and data analysis.

Threats

It is an ambitious project that will imply considerable financial and human resources.

SWGO

Publications

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

- *"New methods to reconstruct Xmax and the energy of gamma-ray air showers with high accuracy in large wide-field observatories"*, R. Conceição, L. Peres, M. Pimenta, B. Tomé, Eur. Phys. J. C 81, 80 (2021)
- *"Muon identification in a compact single-layered water Cherenkov detector and gamma/hadron discrimination using Machine Learning techniques"*, R. Conceição, B. S. González, A. Guillén, M. Pimenta and B. Tomé, Eur. Phys. J. C 81, 542 (2021)
- *"Gamma-ray burst detection prospects for next generation ground-based VHE facilities"*, G. La Mura, U. Barres de Almeida, R. Conceição, A. De Angelis, F. Longo, M. Pimenta, E. Prandini, E. Ruiz-Velasco, B. Tomé, Mon. Not. R. Astron. Soc, Volume 508, Issue 1, November 2021
- *"Probing Gamma-Ray Burst VHE Emission with the Southern Wide-Field-of-View Gamma-Ray Observatory"*, Giovanni La Mura, Ulisses Barres de Almeida, Ruben Conceição, Alessandro De Angelis, Francesco Longo, Mário Pimenta, Bernardo Tomé and Davide Miceli, Galaxies 2021, 9(4), 98
- *"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)

4 International Conference Proceedings

- *"Prospects for VHE monitoring of Gamma-ray Bursts with SWGO"*, G. La Mura, U. Barres de Almeida, R. Conceição, A. de Angelis, F. Longo, M. Pimenta, E. Prandini, E. Ruiz-Velasco, B. Tomé, for the SWGO Collaboration, Proceedings of the Sixteenth Marcel Grossmann Meeting, World Scientific
- *"New methods to reconstruct Xmax and the energy of gamma-ray air showers with high accuracy in large wide-field observatories"*, R. Conceição, L. Peres, M. Pimenta and B. Tomé, Proceedings of 37th International Cosmic Ray Conference - PoS(ICRC2021) 395(2021) 711
- *"Gamma/hadron discrimination using a small-WCD with four PMTs"*, R. Conceição, P. Assis, F. Assunção, A. Bakalova, U. Barres de Almeida, C. Roque Bom, J. Correia, A. De Angelis, L.O. Dias, B. Serrano González, A. Guillén, G. La Mura, N. Lourenço, P. Machado, S. Marques, L. Mendes, M. Pimenta, R. Shellard, B. Tomé and J. Vicha, Proceedings of 37th International Cosmic Ray Conference - PoS(ICRC2021) 395(2021) 707
- *"Monitoring Gamma-Ray Burst VHE emission with the Southern Wide-field-of-view Gamma-ray Observatory"*, G. La Mura, Proceedings of 37th International Cosmic Ray Conference - PoS(ICRC2021) 395(2021) 709

1 Proposal(s) and related studies

- *"The Southern Wide-Field Gamma-Ray Observatory (SWGO): A Next-Generation Ground-Based Survey Instrument for VHE Gamma-Ray Astronomy"*, P. Abreu et al. (SWGO Collaboration),

3 Internal Notes

- *" From many tens of GeV to many tens of PeV: a layout for SWGO"*, P. Assis, A. Bakalová, U. Barres de Almeida, P. Brogueira, C. R. Bom, A. Chiavassa, R. Conceição, A. De Angelis, L. Dias, A. Guillén, B. S. González, G. La Mura, L. Mendes, M. Pimenta, R. C. Shellard, B. Tomé, J. Vicha, HAP-21-003
- *"Tests of the SWGO simulation framework"*, A. Bakalová, R. Conceição, B. Tomé, J. Vícha, HAP-21-004
- *"The Mercedes WCD: a 3-PMTs signle-layer water Cherenkov detector for large cosmic ray ground arrays"*, P. Assis, U. Barres de Almeida, P. Brogueira, R. Conceição, A. De Angelis, B. S. González, A. Guillén, G. La Mura, L. M. D. Mendes, M. Pimenta, R. C. Shellard, B. Tomé, HAP-21-008

1 LIP Students Note(s)

- *"Development of a next generation detector concept to detect astrophysical gamma rays"*, Tatiana Mendes and Matilde Túbal, LIP-STUDENTS-21-27

Presentations

3 Oral presentations in international conferences

- G. La Mura, U. Almeida, A. De Angelis, R. Conceição, F. Longo, M. Pimenta, E. Prandini, E. Ruiz-Velasco, B. Tomé: *"Prospects for VHE monitoring of Gamma-ray Bursts with SWGO"*, 2021-07-07, Sixteenth Marcel Grossmann Meeting,
- R. Conceição, L. Peres, M. Pimenta, B. Tomé: *" New methods to reconstruct Xmax and the energy of gamma-ray air showers with high accuracy in large wide-field observatories"*, 2021-07-13, 37th International Cosmic Ray Conference (Berlin), Online
- R. Conceição for the SWGO Collaboration: *"Southern Wide-field Gamma-ray Observatory: status and prospects"*, 2021-07-26, EPS-HEP Conference 2021, Online

2 Poster presentations in international conferences

- R. Conceição et al., for the SWGO collaboration: *"Gamma/hadron discrimination using a small-WCD with four PMTs"*, 2021-07-16, 37th International Cosmic Ray Conference (Berlin), Online
- G. La Mura, U. Barres de Almeida, A. De Angelis, R. Conceição, F. Longo, M. Pimenta, E. Prandini, E. Ruiz-Velasco, B. Tomé on behalf of the SWGO Collaboration: *"Monitoring Gamma-Ray Burst VHE emission with the Southern Wide-field-of-view Gamma-ray Observatory"*, 2021-07-21, 37th International Cosmic Ray Conference (Berlin), Online

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

- R. Conceição: *"Observatório Pierre Auger e SWGO: Duas janelas para o Universo extremo"*, 2021-11-06, Escola Avançada de Professores em Língua Portuguesa, CERN (Online)

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

- Mário Pimenta: Matilde Tubal, Tatiana Mendes (supervisors : Ruben Conceição, Bernardo Tomé): *"Development of a next-generation detector concept to detect astrophysical gamma-rays"*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online

3 Seminars

- Mário Pimenta: *"Um Observatório de raios gama com grande abertura angular nos Andes"*, 2021-06-01, Colóquio Centro Brasileiro de Pesquisas Físicas, Online
- Mário Pimenta: *"A Gamma Ray Wide-Field Observatory at the Andes: a new window to the Universe"*, 2021-06-15, Instituto de Física de Partículas y del Cosmos (IPARCOS) public online colloquium, Online
- Mário Pimenta: *"The Southern Wide Field Gamma Ray Observatory (SWGO): a new window to the Universe"*, 2021-09-30, LIP Seminar, Online

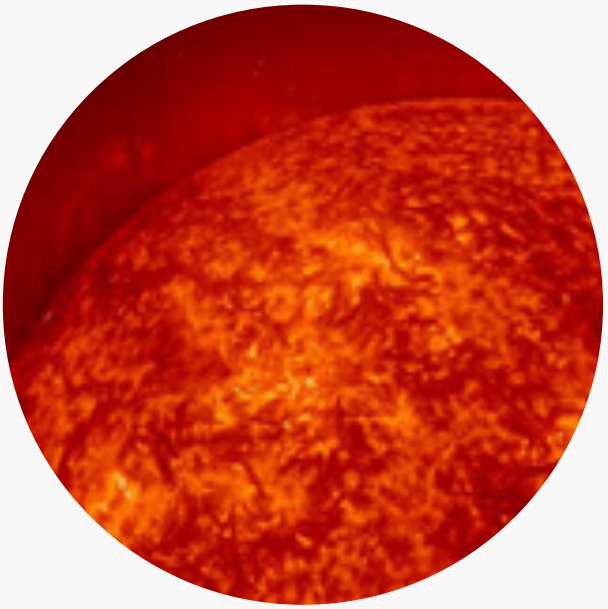
Theses

2 PhD

- Borja González: *"A next-generation gamma-ray observatory powered by Machine Learning techniques"*, 2020-12-15 , (ongoing)
- Lucio Gibilisco: *"Reaching for PeVatrons with the future Southern Wide-field Gamma-ray Observatory"*, 2021-12-31 , (ongoing)

2 Master

- Laura Peres: *"A novel energy reconstruction for high-energy gamma-ray wide field of view observatories"*, 2019-07-01 / 2021-11-26, (finished)
- Pedro Costa: *"Detection of astrophysical neutrinos with a gamma-ray observatory"*, 2020-09-14 / 2021-11-26, (finished)



[Dark matter and neutrino]

DarkMat

Neutrino

SHiP

DARKMAT

Participation in dark matter experiments: LUX and LZ

Principal Investigator:
Isabel Lopes (67)

9 ***Researcher(s):***
Alexandre Lindote (84), Cláudio Silva (64), Elias Asamar (100), Francisco Neves (64), Helmut Wolters (20), José Pinto da Cunha (41), Paulo Brás (99), Salvatore Davide Porzio (33), Vladimir Solovov (44)

2 ***Technician(s):***
Américo Pereira (8), Nuno Carolino (8)

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

8 ***Master Student(s):***
Andrey Solovov (31), Carlos Neto (25), David Carreira (25), Fátima Alcaso (50), Henrique Almeida (26), Ricardo Cabrita (41), Sandro Saltão (26), Susana Castanheira (83)

7 ***Undergraduated Student(s) and Trainee(s):***
Carlos Roxo, Diogo S. Gorgulho, Francisco Casalinho, Francisco Pais, Gonçalo Ivo, Paulo Pires, Tiago Miguel Martins

Total FTE:
10.5

Articles in international journals:	**2** Direct contribution **3** Indirect contribution
Notes:	**1** Internal note
International conferences:	**1** Oral presentation **2** Posters
Collaboration meetings:	**5** Oral presentations
Advanced Training Events:	**1** Oral presentation
Seminars:	**1** Seminar
Completed theses:	**1** PhD **3** 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 the xenon detectors. Since 2002, the group has participated in several word-leading WIMP direct detection experiments: ZEPLIN II, ZEPLIN III, LUX and LUX-ZEPLIN (LZ), of which LIP is a founding member. Presently, the group is involved in three projects that, although distinct, are closely related: i) LZ experiment; ii) Migdal project; iii) R&D project on optical properties of reflecting surfaces.

i) LZ will be the most sensitive dark matter experiment for WIMPs with masses from 10 GeV to 10 TeV, with a predicted sensitivity of 1.4×10^{-48} cm^2 for WIMP mass of 40 GeV in a 1000 live-days run and 5.6 ton fiducial mass. Due to its extremely low background, LZ can also be used for other studies, such as the search of other dark matter candidates and Xe rare and forbidden decay modes. The first science run started in the last days of 2021, lasting for about 2 months. The group is contributing to several areas of 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).
- Its multiple contributions to 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 of 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 experiments to the sub-GeV mass region. The experimental set-up assemblage is being completed.

iii) The R&D project on the study of optical properties of reflecting surfaces aims to measure the fluorescence and the reflectance for the xenon light of PTFE in a liquid interface, including the study of the latter as a function of the temperature. The reflectance measurements were completed and data analysis is being carried out. The fluorescence measurements are about to start.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Cláudio Silva		50.000 €	2016-11-01 / 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	239.807 €	2018-09-01 / 2021-05-31	PTDC/FIS-PAR/28567/2017 / Participation in dark matter experiments LZ
Isabel Lopes	Francisco Neves	249.948 €	2021-06-01 / 2024-05-31	PTDC/FIS-PAR/2831/2020 / Participation in the LUX-ZEPLIN experiment

DarkMat

Overview

In 2021, the group was involved in three different but closely related projects: LZ experiment; Migdal project; R&D project on optical properties of reflecting surfaces.

The main lines of work (and group members involved) of the LIP group in the framework of LZ are the following:

- **Physics Beyond Dark Matter search with LZ detector**: search for neutrinoless beta decay in ^{136}Xe and ^{134}Xe, as well as other Xe rare decays such as double capture in ^{124}Xe and ^{126}Xe, with a strong focus on the use of machine learning algorithms for improving the signal-to-background discrimination (A. Lindote, C. Silva, P. Brás, F. Neves, E. Asamar, S. Castanheira, F. Alcaso).
- **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 (F. Neves, P. Brás, C. Silva, G. Pereira, V. Solovov and A. Solovov).
- **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 (F. Neves, G. Pereira).
- **Background modelling and accounting** (A. Lindote, C. Silva, H. Wolters).
- **LZ Control system (CS)**: full responsibility for the part of the slow control based on Ignition (V. Solovov, R. Cabrita and G. Pereira).

In 2020, a group of UK and LIP researchers participating in LZ set a new research project to prove the existence of the Migdal effect. The project is led by the Rutherford Appleton Laboratory (RAL) and involves researchers from Imperial College London (ICL), CERN (Gas Detectors Development Group), LIP, ISIS, University of Birmingham, University of Oxford, University of Sheffield and University of New Mexico (USA), in a total of about 40 people.

The project aims at observing and measuring for the first time the Migdal effect in nuclear scattering, which would allow extending the direct dark matter searches to lower masses (sub-GeV range). This effect is predicted theoretically but was not confirmed experimentally so far.

The LIP team involved in this project includes F. Neves (coordinator), E. Asamar, A. Lindote, V. Solovov and I. Lopes. The group has responsibilities in the simulations, the development of the data acquisition software and the associated user interface, the development of the event reconstruction algorithms and background assessment.

Regarding R&D, there is a project, whose PI is C. Silva (IF/00877 /2015/CP1311/CT0002), that aims to model, simulate and measure the fluorescence and the reflectivity of rough and diffuse surfaces (C. Silva, R. Cabrita, D. Pozio, V. Solovov).

Assessment of the past year: objectives vs. achievements

The first LZ science run started in December 2021 and it aims to take data during 60 live days.

Due to the delay introduced by the COVID-19 pandemic, the tasks foreseen in our plan for 2021 that required real data could not be carried out.

Below are listed the main objectives that were achieved.

I. LZ Experiment

1. LZAP

- The pulse finder and classifier modules developed by the LIP-Coimbra group are at the base of all the LZ subsequent analysis.Their task is to find meaningful structures (e.g. pulses) out of the complex LZ detector raw output and classify them. Those modules were improved to handle real LZ detector data and were successfully tested during the detector commissioning.
- Photon Counting Module: a new method to correct the pile-up effects in discrete signals was developed. It is purely statistical, applied to each PMT individually, and depends only on the observed number of counts and not on the pulse areas as before. Additionally, we collaborated in the improvement of the current method to count photons. In the previous method, the pulses above a specific threshold were counted as a single detected photon. In the new method, we also look for subpeaks, i.e. inflexions in the observed amplitude of the signal. We used real LZ data to test both the photon counting method and the pile-up correction.
- Position reconstruction module
  - The Mercury position reconstruction package was refactored to facilitate its integration into LZ analysis software, including LZap, UPM and ALPACA (Analysis Lz PACkAge) as well into a standalone Python module
  - First experimental LRFs (light response functions of the photomultipliers) were successfully reconstructed from background and calibration data
  - A novel Mercury-based energy reconstruction technique was developed and validated with calibration data from multiple sources
  - A novel compressed sensing technique was developed for reconstruction of multi-vertex events in a TPC
  - An efficient technique for end-to-end mapping of the physical PMTs to the DAQ channels using solely experimental data was developed and successfully used to verify correctness of cabling of the LZ PMT arrays.

2. UPM

In 2021, the Underground Performance Monitor (UPM) related work was mostly driven by the commissioning and testing of the various LZ sub-systems (e.g. TPC, OD, DAQ). The UPM development team (lead by Francisco Neves and entirely constituted by LIP members) worked in close connection with the detector coordinators to respond quickly with the required analysis tools to better understand and monitor LZ in real time, decreasing substantially any operation downtime. In addition to the large number of small adjustments and improvements in almost all implemented algorithms/analysis, the highlights of the work are:

- Added analysis monitors for the fast sensors (e.g loop antennas and TPC microphones).
- Added livetime analysis both based in GPS and random triggered events.
- Added alarms logic for several analysis monitors to trap unstable detector conditions (e.g abnormal acquisition rates, DAQ malfunctioning).
- Upgraded the pulse finder and classifier algorithms to meet the acquisition/detector conditions (e.g grids HV, PMT response).
- Added the Mercury position reconstruction algorithm as a more precise alternative to the existing recursive weighted CoG reconstruction.
- Complete reorganization of the (high number of) analysis outputs for better handling/visualization of data at the level of the user interface.
- Several improvements and optimizations in the web based UPM Graphical User Interface (GUI) to improve user data handling experience.
- Started the deployment of an offline UPM server at Rochester as a means to access UPM historical data without disturbing real time analysis.

3. Xe-136 NDBD

- The study of the sensitivity of a larger (3rd generation, G3) xenon TPC for $0\nu2\beta$ in ^{136}Xe continued in 2021. A reduction of more than 60% of the gamma-ray background from contamination in materials used in detector construction compared to LZ can realistically be achieved with careful material selection. Preliminary results using this gamma background estimation and a toy MC show that a 3rd generation xenon TPC with a mass approaching 100 tonnes can reach a world leading sensitivity after 10 years of operation and directly compete with dedicated experiments such as nEXO.
- The Multiple Scatter (MS) discrimination capability of LZ in the vertical (z) axis is currently being studied by a Master student, who is also pursuing the development of dedicated MS discrimination algorithms for LZ. These algorithms will be tested once data from the first science run of LZ is available.
- The Profile Likelihood Ratio (PLR) analysis framework for the NDBD sensitivity studies is still ongoing, with the developments focusing on the preparation of the sensitivity studies for a 3rd generation xenon observatory.

4. Xe rare decays

- **$2\nu2\beta$ and $0\nu2\beta$ in Xe-134**: The analysis of LZ to the normal $2\nu2\beta$ and the forbidden $0\nu2\beta$ decays in ^{134}Xe was finalized. The experiment is expected to obtain world leading sensitivities for both decays in just a few months of operation. The paper describing the analysis and results (E. Asamar is the leading author) has been published in Physical Review C.
- **Xe-124 2EC**: The background model of the LZ detector for $2\nu2$EC in ^{124}Xe was finalized, and the discovery potential of the detector to the 3 main decay channels (KK, KL and LL) have been estimated (included in the Master thesis of S. Castanheira). LZ can reach a 5σ discovery level in the KK channel in less than 100 days if the half-life observed by XENON1T of $1.8\text{x}10^{22}$ yr is confirmed. For the KL channel, a 3σ observation should be possible in the same time period (making this the longest lived nuclear process ever observed directly in laboratory), while a 5σ discovery of this channel should be possible in under 1 year of operation. Studies of the dependency of the required exposures with the levels of the dominant backgrounds Kr-85 and Rn-222 were also performed, as well as estimates of the I-125 background during normal operation (expected to be negligible).
- A. Lindote was one of the two coordinators of the collaboration workgroup responsible for studying the Xe rare decays.
- The backgrounds database (DB) was expanded to take into account the higher granularity of background simulations performed by the LZ collaboration for Science Run 1, with existing components being grouped into new subsystems in order to match simulations and provide the required normalizations.
- The Python module to interface the backgrounds DB and the background analysis framework was finalized and is ready for testing with real data. It allows to query the DB for the required normalizations as well as storing and retrieving parameters resulting from the background model fit from the DB.
- The background distribution near the walls depends mainly on the uncertainties of the position reconstruction. We studied the uncertainties of Mercury as a function of both position and S2 pulse size. We also developed a new selection criterion based on the minimum $\chi2$ of the position reconstruction in order to remove multiple scatter events that occur mainly near the walls of the detector.

6. Control System

- Ignition GUI developed by the LIP team is used as a primary user interface for the experiment operations, including remote shifts.
- Control system support was re-organized in order to improve its efficiency:
  - ticket system was implemented.
  - dedicated development meetings were organized.
  - advanced developer training was provided by Guilherme Pereira.
- Last minute integration of several systems required for detector operation (Water tank, Source delivery, DAQ, UPM, Mobile sampling system, Radon monitoring).
- Additional Ignition server was deployed at the surface to be used by remote shifters in order to reduce load on the underground slow control infrastructure.
- G. Pereira continues as the lead Ignition developer.
- Vladimir Solovov continues as Control system coordinator.
- Control system meetings are organized by V. Solovov on a weekly schedule. In total, 47 meetings were held during 2021.

II. Migdal Project

In 2021 the LIP dark matter group has provided essential contributions to design and build the MIGDAL experiment:

- Design of the shielding of the experiment for deuterium-tritium (D-T) and deuterium-deuterium (D-D) neutron sources, as well as the collimators.
- Development of the data acquisition software and user interface.

The group has also contributed to assess backgrounds and to prepare the data analysis, namely:

- Complete the prediction of the background from random track coincidences.
- Propose a method to deconvolute the effect of the gaseous electron amplifiers (GEMs) from the MIGDAL camera images, using the Fourier transform of the image. A proof-of-concept has been presented.

III. R&D on optical measurements of PTFE

1. Measurement with a liquid interface

We upgraded the setup to measure the effect of the liquid interface in the reflectance of different materials. This experiment uses a total integrating sphere that can be filled with different liquids. Then, we measured the effect of the liquid interface on the reflectance of the material that covers the inner surface of the sphere (Spectralon) for several liquids such as water and glycerol and different wavelengths ranging from 250 nm to 500 nm. The experiment was simulated in detail using ANTS2 to assess the effect of the liquid on the reflectance and test different models of diffuse reflection.

2. Measurement of the fluorescence

We finished and tested the new VUV xenon scintillation lamp (λ=175 nm), and we upgraded the setup and acquisition systems which are now fully operational and ready for the fluorescence measurements.

Lines of work and objectives for next year

I - Participation in LZ

1. Profile likelihood analysis of the WIMPs search

We intend to explore the use of Machine Learning algorithms for the Profile Likelihood Ratio (PLR) analysis to obtain a limit or claim a discovery. We propose to explore a new class of algorithms and tools for the process.

2. Xe-136 Neutrinoless double beta decay

In the context of a third generation (G3) xenon TPC, use a PLR statistical analysis for improved sensitivity estimates, exploring the energy and position distributions of the signal and most relevant backgrounds for different detector configurations and background assumptions. Results from this study will be published in a White Paper in the context of Snowmass2021.

- Implement the Multiple Scatter discrimination algorithms currently being developed by a master student into the data processing framework of LZ (LZap). Testing of these newly developed methods and algorithms with data from the first science run of LZ.
- Study of PMT saturation and characterization of its effects on the energy and position resolutions of LZ at the energies of the ^{136}Xe NDBD.
- Use data from the LZ first run to validate and adjust the background model and reassess the sensitivity projections and required exposure to reach world-leading limits.

- Xe-124 2EC:
  - Estimate the sensitivity of LZ to search for the neutrinoless mode of the 2EC decay in Xe-124 ($0\nu 2EC$), an alternative channel to $0\nu 2\beta$ to search for Beyond the Standard Model physics.
  - Use neutron calibrations of LZ to develop a temporal model for the dangerous I-125 background (decay product of Xe-125 produced by neutron capture) in the detector.

- Determine the energy resolution of LZ in the energy region of the Xe-124 2EC KK channel using the I-125 decay peak (67 keV).
- Use data from the first run of LZ to validate the background model (and possible signal) of the Xe-124 2EC KK channel with that estimated in the sensitivity study. Adjust the models and reassess the exposure required to reach a 5σ discovery, as well as the 3σ observation threshold for the KL channel.
- Use data from the longer second science run to publish the KK mode 5σ discovery and KL mode 3σ observation results.

- **$2\nu2\beta$ and $0\nu2\beta$ in Xe-134:**

- Use data from the Mn-54 calibration of the LZ detector to estimate the energy resolution of the detector in the region of the Xe-134 Q-value.
- Use data from the first run of LZ to validate and adjust the background model. Reassess the sensitivity projections and estimate the required exposure to reach world-leading limits.
- Use data from the longer second science run to publish initial world leading exclusion results for the two decay modes (or report the observation of the $2\nu2\beta$ mode).

4. Position reconstruction and PMT response

- Continuous monitoring of the PMT performance (Gain, Quantum efficiency, etc.) during the LZ detector operation.
- Study of the PMT linearity and impact of PMT saturation on the performance of position and energy reconstruction.
- Study of the LZ detector energy resolution for electron recoils in a wide energy range.
- Study the possibility of rejection of the events with partial deposition in one of the dead volumes (one of the most difficult backgrounds) by checking for inconsistencies between S1 and S2 light patterns.

5. Backgrounds: modelling and mitigation

- Use MC simulations and early LZ data to study the possibility to reject background events from Pb-214 in the Rn-222 chain (the dominant background at low energies) using the 4D locations (x,y,z,t) of previous decays in the chain.
- Test the developed tools for the background model (DB, interface module) with data from the first science run.
- Use real data from the first science run of LZ to predict the spatial distribution of the wall backgrounds. A comparison with the LUX wall model will also be performed, to better understand the distributions in space and energy of such events.

6. LZap

Continue to update/upgrade the Pulse Finder algorithms to fine tune their response to the data being acquired.

7. UPM

- Upgrade the UPM to use a SQL database to store and retrieve the analysis output objects.
- Improve the web based UPM GUI to better handle the huge amount of data that will be available through the offline server located at Rochester.
- Continue to maintain and update both the infrastructure and analysis tools as required by the LZ operation/behavior.

II - Experimental study of the Migdal Effect

In 2022 the group will contribute to the first data analysis of the MIGDAL experiment, that will search for the Migdal effect in carbon and fluorine atoms using D-D neutrons. This analysis is scheduled to start in March 2022, and has the potential to be the first observation of the Migdal effect ever. The LIP dark matter group is expected to have a leading role in this work.

Besides, additional data analyses searching for the Migdal effect in different energy regimes (using D-T neutrons) and in other atoms (noble gases such as helium, argon or xenon) may happen in 2022. The LIP dark matter group is also expected to contribute to these data analyses.

III - R&D on optical measurements of PTFE

We plan to finish the analysis of the liquid interface influence on the reflectance of materials and to carry out the PTFE fluorescence measurements for the VUV scintillation light (λ=175 nm) and to publish the results.

Medium-term (3-5 years) prospects

Our activity will proceed along three main directions:

1- 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 deeply 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 plans towards the construction of a third generation WIMP search experiment. The first steps were given towards the formation of a new collaboration, based on LZ and DARWIN, that will build and operate the next-generation liquid xenon detector for WIMP search. A joint workshop took place in April 2021 and an MoU was signed expressing the common understanding that DARWIN and LZ intend to merge to carry out the 3rd generation WIMP search experiment. A joint paper was written: "A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics", arXiv:2203.02309v1 [physics.ins-det] 4 Mar 2022.

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

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. 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 the 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 in Spring/Summer 2022. It has been very difficult to recrute PhD candidates.

Opportunities

LZ is the most competitive dark matter experiment in the world, with a high potential for detecting WIMPs. To participate in such experiment is in itself an opportunity with several components from which we highlight: 1) use and extend our areas of expertise; 2) attract young researchers; 3) open the possibility of participating in other cutting-edge projects.

Threats

The project was funded up to May 2024. However the funding is insufficient to run the project. Although it was fully funded (240 k€ for 3 years), after subtracting an auxiliary researcher contract and the overheads, we have only 26k€/year for all the expenses. This is not enough to support the human resources required by the project (even when there are no expenses with missions, as it presently happens due to the pandemic). It does not allow to support the researchers of the group that ceased their contracts with FCT and/or young researchers that have just completed their PhD and have crucial responsibilities in LZ. 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).

Furthermore, 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, is a permanent threat for the project.

Presently, the pandemic is also a threat as it poses difficulties in traveling even within the USA.

DarkMat

Publications

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

- *"Improving sensitivity to low-mass dark matter in LUX using a novel electrode background mitigation technique"*, D. S. Akerib et al., Phys. Rev. D 104, 012011
- *"Projected sensitivity of the LUX-ZEPLIN experiment to the two neutrino and neutrinoless double beta decays in Xe-134"*, D. S. Akerib et al., Phys. Rev. C 104 (2021) 065501

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

- *"Simulations of events for the LUX-ZEPLIN (LZ) dark matter experiment"*, D. S. Akerib et al. (196 authors), Astropart Phys. 125 (2021) 102480
- *"Constraints on effective field theory couplings using 311.2 days of LUX data"*, D. S. Akerib et al., Phys. Rev. D 104, 062005
- *"Projected sensitivities of the LUX-ZEPLIN experiment to new physics via low-energy electron recoils"*, D. S. Akerib et al. (196 authors), Phys. Rev. D 104 (2021) 092009

1 Internal Note(s)

- *"Pulse Finder: technical details (LZap-5.3.8)"*, F. Neves, LZ technical note

Presentations

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

- Paulo Brás: *"Sensitivity of the LUX-ZEPLIN experiment to rare Xenon decays"*, 2021-09-08, PANIC - Particles an Nuclei International Conference: PANIC 2021, Online

2 Poster presentations in international conferences

- Alexandre Lindote: *"Background model and science reach of the LUX-ZEPLIN (LZ) experiment"*, 2021-09-07, PANIC - Particles an Nuclei International Conference: PANIC 2021, Online
- Elias Asamar: *"The MIGDAL experiment: towards the first observation of the Migdal effect"*, 2021-09-07, PANIC - Particles an Nuclei International Conference: PANIC 2021,

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

- Guilherme Pereira: *"The nervous system of the LUX-ZEPLIN detector"*, 2021-06-28, 4th doctoral Congress in Engineering (DCE21), Online

1 Seminar(s)

- Alexandre Lindote: *"Using two-phase xenon detectors to search for Dark Matter"*, 2021-05-27, Seminar at Departamento de Física, Universidade de Coimbra

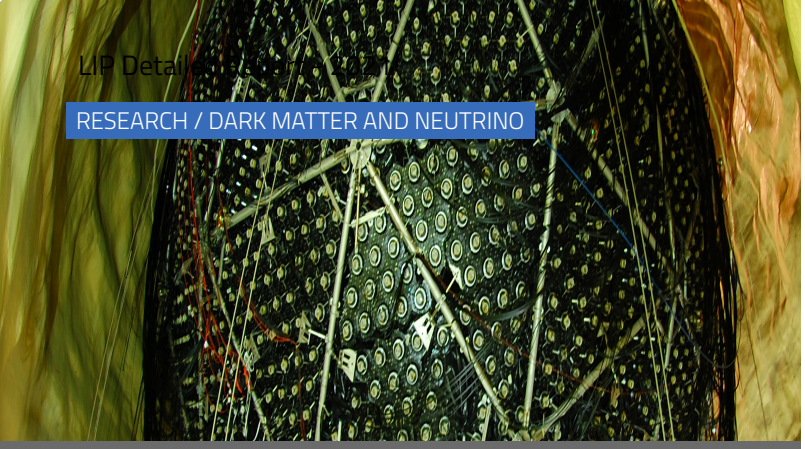
Theses

2 PhD

- Paulo Brás: *"Sensitivity to the 0νββ decay of 136Xe and development of Machine Learning tools for pulse classification for the LUX-ZEPLIN experiment"*, 2015-10-01 / 2021-02-24, (finished)
- Guilherme Pereira: *"Data processing and Human Machine Interface for the monitoring and control system of LZ dark matter experiment"*, 2018-03-15 , (ongoing)

8 Master

- Ricardo Cabrita: *"Efeito do um Interface Líquido na Reflexão de Superfícies Difusoras"*, 2019-09-15 / 2021-03-30, (finished)
- Andrey Solovov: *"Development of analysis techniques for the identification of 0v2ß event topologies and their characterisation"*, 2017-09-01 / 2021-07-21, (finished)
- Susana Castanheira: *"Discovery potential of the LZ detector to the double electron capture decay of Xe124"*, 2019-09-24 / 2021-12-07, (finished)
- Fátima Alcaso: *"Design and optimisation of a xenon TPC with SiPM readout for neutrinoless double beta decay studies"*, 2019-09-15 , (ongoing)
- Henrique Almeida: *"Searches for neutrino and neutrino less 2EC decay modes in Xe-124 with the LZ detector"*, 2021-09-01 , (ongoing)
- Sandro Saltão: *"Optimisation of the vertical separation of multiple scatter events in the LZ detector with applications in the sensitivity to the 0ν2β decay of Xe-136"*, 2021-09-01 , (ongoing)
- Carlos Neto: *"Redes neuronais para deteção de objetos no contexto de navegação natural"*, 2021-09-15 , (ongoing)
- David Carreira: *"Object/Human Detection and Follow Me"*, 2021-09-15 , (ongoing)



NEUTRINO

Neutrino Physics

Principal Investigator:
José Maneira (100)

7 ***Researcher(s):***
Amélia Maio (15), Fernando Barão (25), Francisco Neves (15), Nuno Barros (99), Sofia Andringa (67), Valentina Lozza (99), Vladimir Solovov (25)

1 ***Technician(s):***
Rui Alves (0)

2 ***PhD Student(s):***
Ana Sofia Inácio (99), Matthew Cox (66)

1 ***Master Student(s):***
João Carlos Antunes (70)

4 ***Undergraduated Student(s) and Trainee(s):***
André Soares, Maximilien Bernard , Riccardo Dallavalle, Teresa Oliveira Miranda

Total FTE:
6.8

Articles in international journals:	**2** Direct contribution **5** Indirect contribution
Notes:	**2** LIP Students notes
Proposals:	**1** Proposal(s) and related studies
International conferences:	**2** Oral presentations
National conferences:	**1** Oral presentation
Nat.& Internat. meetings:	**1** Oral presentation
Collaboration meetings:	**17** Oral presentations
Advanced Training Events:	**2** Oral presentations **1** Student presentation
Seminars:	**7** Seminars **5** Outreach seminars

Executive summary

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. The group joined the Sudbury Neutrino Observatory (SNO) experiment in 2005 and is a founding member of the SNO+ collaboration. The main goal of SNO+, that reuses the SNO detector, replacing the heavy water by liquid scintillator, is the search for the neutrinoless double-beta decay (DBD) of ^{130}Te. In addition, several other physics topics are part of its program: antineutrinos from nuclear reactors and the Earth's natural radioactivity, solar and supernova neutrinos, and searches for new physics.

The group has participated in the construction of calibration systems and is currently very active in the data analysis of the water and scintillator fill (half-full and full) phases, with leadership or strong contributions to physics analyses (backgrounds and antineutrino studies) and calibrations. The scintillator fill was completed in 2021 and preparations are ongoing for the Tellurium loading, expected to start later in 2022.

In 2018, the group joined the DUNE collaboration, with the goal of participating in the leading neutrino physics experiment of the next decade. The activities are focusing on the design and construction of the far detector calibration systems and in the operation and analysis of the ProtoDUNE detectors at CERN. Testing the designs of the calibration systems at ProtoDUNE-II is a priority for the next few years.

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 development and R&D for a future one (DUNE).

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Valentina Lozza		50.000 €	2017-01-01 / 2022-03-31	IF/00248/2015/CP1311/CT0001 / Expl. 2015_VL - IF/00248 /2015/CP1311/CT0001
José Maneira	Sofia Andringa	130.000 €	2019-09-01 / 2021-08-31	CERN/FIS-PAR/0012/2019 / Underground Neutrino Physics: Participation in the DUNE and SNO+ experiments
José Maneira	Nuno Barros	90.000 €	2021-09-01 / 2023-08-31	CERN/FIS-PAR/0014/2021 / DUNE_Calibração de ProtoDUNE-II no CERN
Nuno Barros	Valentina Lozza	231.005 €	2021-12-01 / 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:

- Detector calibration and background characterization
  - Measurement of detector model parameters using optical calibration source data and intrinsic backgrounds.
  - Design, fabrication and deployment preparation of low energy gamma sources for the scintillator phase.
  - Coordination of the analysis of the backgrounds in the scintillator phases (half-full and full detector); coordination of studies for the scintillator+Te phase, analysis of water phase.
- Analysis of physics data
  - Antineutrinos: complete the analysis of the partial fill data and move towards full fill data. Evaluate neutron tagging efficiency using external calibration sources and intrinsic backgrounds.
  - 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.
  - Participation in the measurement of the neutron cross section in LAr, crucial for the design of a Pulsed Neutron Source.
  - Interface of the calibration systems with DAQ, slow controls and computing, including design of a dedicated electronics board.
- ProtoDUNE@CERN commissioning and analysis
  - ProtoDUNE laser calibration systems design, construction, installation, operation, simulation and analysis.
  - ProtoDUNE data analysis: cosmics and beam data, neutron response.

List of internal SNO+ leadership responsibilities: Partial Fill (VL) and Water phase (NB) Analysis Coordinators, Physics Analysis Coordinator (VL), Antineutrino Physics (SA), Backgrounds (VL) and Optical Calibration (NB, JM) Working Group and Calibration Source Review Committee (JM, VL is a member) leaders. In addition we are members of the SNO+ Executive Committee (JM), Analysis Coordination Committee (JM, VL), Middle Level co-coordinator (VL) and responsible for software documentation, within the software validation group (ASI).

List of internal DUNE leadership responsibilities: Calibration and Cryogenic Instrumentation Consortium (JM), ProtoDUNE-I Single Phase trigger (NB).

Assessment of the past year: objectives vs. achievements

SNO+

In terms of the water phase SNO+ data analysis, we achieved most of the goals we had planned for 2021:

- We published the optical calibration paper, driven fully by ASI (PhD student).
- We nearly completed the antineutrino analysis in water (half of the dataset has been unblinded) and the paper is in preparation. We improved the analysis of search for nucleon decay into invisible channels using the more recent low background dataset and the corresponding paper is in the internal editorial review phase. The analysis of solar neutrinos in the water low background dataset is nearly completed and a paper is in preparation.

As for operations at SNOLAB, the scintillator fill was completed in April 2021, despite delays caused by COVID-19. This allowed us to achieve several of the goals planned for 2021. Our group had a large contribution in the data analysis of the partial fill data (8B solar neutrinos, (alpha,n), DBD target-out, background evaluation, calibration) and in its coordination (backgrounds, overall analysis):

- Completed the ^{8}B solar neutrino analysis in the partial fill phase (365 t of scintillator) and the results have been presented at the conference PANIC2021.
- Calibrated the time and energy response of the partial fill dataset using internal radioactive sources (BiPo214).
- Completed the (alpha,n) analysis in partial fill and the corresponding first antineutrino measurement in partial fill. A paper is currently being written.
- Target-out measurement in preparation for the Te-loaded phase during the partial fill and the full scintillator fill has shown a good understanding of the backgrounds contributing to the region of interest. All backgrounds are within expectation, with the larger contributions being due to sources that will not be present in the Te phase (plastic tube for water extraction, internal water in partly filled detector).

- We have followed the evolution of the backgrounds as we continued to add scintillator and during the phase of scintillator recirculation for PPO (wavelength shifter) addition.

DUNE

In DUNE we have mostly achieved all our goals related to detector calibration:

- After having completed the main aspects of the design for the ionization laser calibration system for the DUNE far detector, in 2021 we proceeded towards the demonstration of that design in ProtoDUNE.
- Thanks to LIP's Mechanical Workshop and Detector Lab, we have produced and tested at LIP the electrical break, straight and eccentric nipple assemblies for periscope #2, plus the two straight nipples for periscope #1. We have also produced and tested all the 5 mirror pads for the laser beam location system. After testing, most of these components were shipped to LANL for the full system assembly.
- We have procured several optical components, including custom-made long quartz tubes, plus several types of mirrors.
- We have received on loan from LANL one rotary stage, plus motor and driver, that we used for several leak-checking tests, and development of the motor/encoder control software.
- We have prepared a setup for cold tests of mirror reflectivity at 266 nm, and used it.
- Progressed on the design of the interface electronics between the laser system and the DUNE DAQ and Slow Control system:
  - Identified the necessary hardware interfaces to all the laser system components.
  - Procured the necessary off-the-shelf electronics parts (FPGA, Motherboard).
  - Implemented prototypes for the FPGA logic and slow control server.
- Initiated the implementation of the Calibration Control Software, allowing to visualise the expected laser path based on an input direction using a CAD rendering of the detector.
- Implemented control software for the rotary stage motors using a microcomputer (RPi).
- Performed leakage tests of the rotary stage during movement to assess the optimal movement speed and operation mode of the calibration system.

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.

Project management is also a relevant part of the group's activities since the Calibration and Cryogenic Instrumentation Consortium Lead is a group member (JM). 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

We participated actively in a few other publications:

- Measurement of solar hep neutrinos with a re-analysis of the full SNO dataset, now published (one of stated 2020 goals). NB was coordinator of this analysis.
- Preparation of an (alpha,n) paper for future measurements under the hat of the (alpha,n) group formed in Madrid. Presentation of the requirements for the cross section measurements at a dedicated virtual IAEA meeting (VL).

NB was also moderator of breakout room sessions of the ECFA Roadmap Process Liquid Detectors group (Task Force 2).

Lines of work and objectives for next year

SNO+

In 2022, after completing the PPO addition operations, a period of background counting will follow, and Tellurium-loading operations are planned for late 2022/2023 (starting with the first cocktail component, DDA). This period of background counting is crucial for the scientific strategy of SNO+, determining whether further purification campaigns are necessary before the Te loading.

Our group will play a central role in the analysis of those 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

- Calibrate the SNO+ detector with full nominal PPO concentration with internal and external sources, with particular importance of the Laserball source for obtaining the scintillator optical properties.
- Continue to monitor purity, optical quality (light yield, quenching) of the scintillator during PPO addition. The earlier we reach a full understanding of the pure scintillator, the earlier we can add the components of the Tellurium cocktail.

Water Phase Analysis

- Complete the few missing papers: namely papers on antineutrinos, backgrounds (focusing on alpha,n predictions and external background measurements), solar and nucleon decay (most already written).

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 of the background related to the PPO addition and scintillator recirculation. This analysis is crucial to understand the sources of Rn ingress 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; plan a DBD workshop in Lisbon for June 2022 (COVID-19 allowing, invitations sent, first organization meetings have been held).

DUNE

In 2022 the main activities will consist in finalizing the design and installation of the ionization laser system for ProtoDUNE-2.

We will continue to contribute to the design, construction and tests of the ionization laser calibration system. A series of operational tests will be carried out at LANL in the beginning of 2022.

A series of aspects will be finalized during 2022:

- Finalize the design and produce 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.

Additionally, once the integration tests are completed at Los Alamos, the various components of the ionization laser will be shipped to CERN and installed in the horizontal drift cryostat of ProtoDUNE-2:

- Installation of single and dual-rotary system periscopes in ProtoDUNE-2 cryostat before the cryostat is sealed (Q2 2022).
- Commissioning of the full system at ProtoDUNE-2 in standalone mode (without relying on integration with DAQ).
- Perform integration tests with DAQ, Slow Control and timing system in Q4 of 2022.

With respect to the neutron calibration work, we will finalize the analysis of data from the ARTIE experiment (interaction of neutrons with liquid argon) and a publication is expected soon. We will proceed with the analysis of the Pulsed Neutron Source data collected at ProtoDUNE in 2020, and the preparation for a next test in 2023.

In addition, we will continue to implement a detailed modelization of the laser-based ionization of liquid argon in the DUNE simulation software infrastructure (LarSoft), in collaboration with colleagues from Brazil. We aim to simulate the UV laser in ProtoDUNE and its usage for E-field mapping and detector calibration.

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 2021-2022, and Te-loaded scintillator from 2023 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 a pulsed neutron source, dedicated to the low energy response. Operations and data analysis of ProtoDUNE are also strategic goals for the longer-term development of an expertise in LAr detectors 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 and programming.

Weaknesses

Two of the group's researchers have non-permanent positions, despite having crucial responsibilities in SNO+. The group has a very "top-heavy" structure, with eight researchers and only two PhD students (one near the end and one in co-supervision with Univ. of Liverpool). This is a common situation at LIP, and our group is engaging with coordinated efforts to attract students at undergraduate and master levels.

Threats

SNO+ is a high-risk, high-gain experiment: the loading of large quantities of very pure Tellurium presents a major technical challenge. A difficulty during filling may result in schedule slippage, compromising the impact of the scientific output in a competitive community.

DUNE is a very large international collaboration, internally competitive, and so a relevant position of LIP within DUNE is a demanding 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 shift of SNO+ towards data-taking and physics analysis provides excellent opportunities for MSc theses, potentially attracting new students. With the start of the scintillator phase, new topics are explored.

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

A first CERN-fund project, covering both experiments, was approved for two years, having come to an end in 2021. A new R&D project for SNO+ has been approved for three years. A CERN-fund project for DUNE was also recommended for funding for two years.

Neutrino

Publications

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

- *"The SNO+ Experiment"*, M.R. Anderson et al. (SNO+ Collaboration), JINST 16 P08059 (2021)
- *"Optical calibration of the SNO+ detector in the water phase with deployed sources"*, M.R. Anderson et al. (SNO+ Collaboration), JINST 16 P10021

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

- *"Searching for Solar KDAR with DUNE"*, A. Abed Abud et al. (DUNE Collaboration), submitted to JCAP
- *"Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC"*, A. Abed Abud et al. (DUNE Collaboration), Accepted for publication by JINST
- *"Prospects for Beyond the Standard Model Physics Searches at the Deep Underground Neutrino Experiment"*, B. Abi et al. (DUNE Collaboration), Eur. Phys. J. C 81, 322 (2021)
- *"Development, characterisation, and deployment of the SNO plus liquid scintillator"*, SNO Collaboration (224 authors), J. Instrum. 16 (2021) P05009
- *"Supernova Neutrino Burst Detection with the Deep Underground Neutrino Experiment"*, DUNE Collaboration (973 authors), Eur. Phys. J. C 81 (2021) 423

1 Proposal(s) and related studies

- *"Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics"*, B. Abi et al. (DUNE Collaboration), Fermilab report: FERMILAB-PUB-20-025-ND

2 LIP Students Notes

- *"212Bi -208Tl tagging"*, Maximilien Bernard, Internship Report
- *"Neutron data from the SNO+ neutrino detector"*, André Soares and Teresa Miranda, LIP-STUDENTS-21-25

Presentations

2 Oral presentations in international conferences

- J. Maneira for the DUNE Collaboration: *"DUNE and LBL Neutrino Program"*, 2021-07-13, DPF21 - Meeting of the Division of Particles and Fields of the American Physical Society, Online (Florida, USA)
- A. S. Inácio for the SNO+ Collaboration: *"Status and Prospects of the SNO+ Experiment"*, 2021-09-08, PANIC - 22nd Particles and Nuclei International Conference, Online (Lisbon)

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

- Valentina Lozza: *"(alpha, n) reactions in low-background neutrino experiments"*, 2021-11-08, IAEA Technical Meeting on (alpha,n) nuclear data evaluation and data needs, virtual

1 Presentation(s) in national conference(s)

- Matthew Cox: *"Alpha – Neutron Background Characterisation Within the SNO+ Detector "*, 2021-04-12, Joint APP, HEPP and NP Conference, Online

2 Oral presentations in advanced training events

- A. S. Inácio: *"Astroparticle Physics Overview"*, 2021-05-05, Third Summer Particle Astrophysics Workshop, online
- J. Maneira: *"Understanding the Universe with Neutrinos and Astroparticles"*, 2021-07-15, 6th Lisbon mini-school on Particle and Astroparticle Physics, Online

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

- André Soares e Teresa Miranda: *"Neutron data from the SNO+ neutrino detector"*, 2021-09-13, LIP Internship Program 2021: LIP Internship Program 2021 Final Workshop, LIP, online

7 Seminars

- N. Barros: *"The Goals and Status of the DUNE Experiment"*, 2021-02-11, LIP Seminar, Online
- Nuno Barros: *"The Goals and Status of the DUNE Experiment"*, 2021-02-14, LIP Seminar, LIP
- A. S. Inácio: *"The Optical Calibration of SNO+ with the laserball"*, 2021-03-11, University of Sussex Physics Department Seminars, Online (Brighton, UK)
- A. S. Inácio: *"Ton-scale search for double-beta decay"*, 2021-03-29, King's College London Physics Department Seminars, Online (London, UK)
- Nuno Barros: *"The DUNE Experiment: Neutrinos and the matter-antimatter asymmetry"*, 2021-04-14, , Universidade de Coimbra
- Valentina Lozza: *"The SNO+ experiment: from water to scintillator fill"*, 2021-11-18, , IKTP, TU Dresden
- Valentina Lozza: *"Cosmogenic induced background in materials for rare event searches"*, 2021-12-09, , virtual

5 Outreach seminars

- Nuno Barros: *"Neutrinos: Aqui, aí e em todo o lado!"*, 2021-02-27, Masterclasses@FCUL, FCUL
- J. Maneira: *"A antimatéria desapareceu por causa dos neutrinos?"*, 2021-05-17, Pint of Science Portugal 2021, online
- José Maneira: *"Neutrinos"*, 2021-09-30, Give me more Quantum,
- Valentina Lozza: *"The SNO+ Experiment: or how to have fun with the neutrinos"*, 2021-10-27, TeilchenWert afternoon for high school and first year University students, IKTP, TU Dresden (Germany)
- Valentina Lozza: *"The SNO+ Experiment: or how to have fun with the neutrinos"*, 2021-11-22, Meeting for physics teachers organised by IKTP, TU Dresden, TU Dresden (Germany)

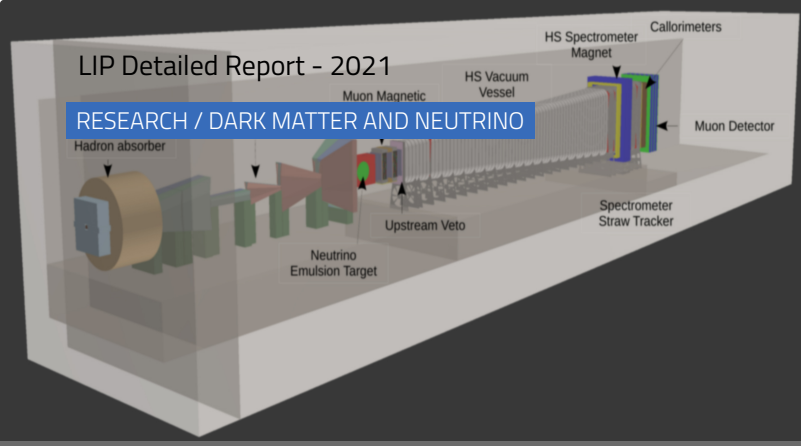
Theses

2 PhD

- Ana Sofia Inácio: *"Measurement of the 130 Te Two-Neutrino Double Beta Decay Half-life with the SNO+ Experiment"*, 2018-03-01, (ongoing)
- Matthew Cox: *"Background characterisation for water and scintillator phases of SNO+"*, 2018-10-01 , (ongoing)

1 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 , (ongoing)



SHIP

Search for Hidden Particles

Principal Investigator:
Nuno Leonardo (25)

3 ***Researcher(s):***
Alberto Blanco (10), Paula Bordalo (30), Sérgio Ramos (30)

2 ***Technician(s):***
João Saraiva (15), Luís Lopes (5)

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

2 ***Undergraduated Student(s) and Trainee(s):***
André Branco, Henrique Santos

Total FTE:
2.2

Articles in international journals:	**1** Indirect contribution
Notes:	**1** LIP Students note
Proposals:	**1** Proposal(s) and related studies
Collaboration meetings:	**3** Oral presentations
Advanced Training Events:	**1** Student presentation
Completed theses:	**1** MSc

Executive summary

The search for particles with feeble interaction strength is compelling. Theoretical scenarios that extend the Standard Model (SM) for addressing Dark Matter and many other aspects of fundamental physics contain such Feebly Interacting Particles (FIPs).

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 SHiP experiment at CERN is being designed to search for FIPs and to measure neutrinos. SHiP constitutes a general-purpose experimental facility 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.

The SND@LHC experiment is the most recent LHC experiment. It stems from the SHiP neutrino detector. It shall utilize the potential of the LHC as a neutrino factory to perform measurements with all three neutrino flavours, providing first observations of collider neutrinos, and in a hitherto unexplored energy and kinematic range.

The LIP group is involved in the preparation of the SHiP experiment and in the construction of the SND@LHC experiment. The year of 2021 saw the approval of the SND@LHC experiment by CERN, through its construction, with LIP as a founding member. The new experiment is being installed and commissioned, aiming at taking first data already this year, with the start of Run 3 of the LHC.

The LIP group is involved in both data analysis and detector development. The tasks of the group are achieved in a close collaboration between the Lisbon and Coimbra nodes of LIP. The group attracts and contributes to the advanced training of undergraduate students, in both analysis and hardware. Multiple internship students have taken part in the projects, an MSc thesis has been completed, and a PhD has started.

The search for feebly interacting particles provides a vibrant experimental endeavour in the pursuit of new physics beyond the standard model over the coming years. The discovery of collider neutrinos will be a milestone, and shall offer novel probes in the exploration of the flavour sector. The aim includes to contribute in novel ways to the exploration of the full physics potential of the LHC.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Nuno Leonardo	Alberto Blanco	40.000 €	2022-03-04 / 2024-03-03	CERN/FIS-INS/0028/2021 / LHC-SND_Participação na experiência SND@LHC do CERN

SHiP

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 different experiments. The physics focus is on flavour, neutrinos and FIPs.

Heavy flavour is produced abundantly in high energy and intensity hadron interactions (fixed target or 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.

The Search for Hidden Particles (SHiP) 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. The detector will nominally operate in a new beam dump facility (BDF), where it will use the high-intensity beam of 400 GeV protons from the SPS accelerator. The ESPPU process highlighted the physics potential of the experiment, while recognizing difficulties to financially resource BDF. As a result R&D is actively ongoing towards optimizing the design of the facility.

The Scattering and Neutrino Detector at the LHC (SND@LHC) is a recently approved compact and stand-alone experiment that will utilize the potential of the LHC as a neutrino factory, to perform measurements with all three neutrino flavours, that are produced in the collisions, alongside a first, unprecedented observation of collider neutrinos. The detector is based on SHiP's neutrino detector, being installed off-axis, 480 meters downstream from the ATLAS interaction point.

The LIP group currently carries out activities in both detector and physics analysis fronts in the framework of SHiP and SND@LHC. The group has continued to work without funding. However, a funding project has been now approved.

Assessment of the past year: objectives vs. achievements

The year of 2021 has been determining for the group. While the SHiP and BDF timelines have been affected, with redirected effort to the optimization of the facility at SPS, the SND@LHC experiment has been proposed and approved by CERN for fast construction and exploitation. The group has been fully engaged in the construction and commissioning of the new experiment at the LHC.

Following submission of the Technical Proposal at the beginning of the year, the SND@LHC experiment was readily approved by the LHCC, and green-lighted for construction in March 2021. The MoU for construction followed, having LIP as a founding institution. In particular, LIP became a Collaborating Institution with responsibility for the Muon System of the experiment.

LIP played a central role in the construction of the Muon system of SND@LHC. The mechanical parts of the system (both Upstream and Downstream subsystems) were produced almost entirely by the Mechanical Workshop of LIP. Design optimizations and adjustments were implemented with our collaborators at Berlin, Bologna, Mainz and Zurich. Following intensive production and test assembling in Coimbra over the Summer period, the detector structures were shipped to a lab at CERN. There the various detector components were assembled and tested. In the Fall, a commissioning phase followed, including data taking with two test beams. The system was finally transported to and installed in its final location (TI18) in the LHC tunnel.

Following the production phase at LIP, group members were actively involved in the assembly of the detector at CERN, as well as in ensuing commissioning, and participated in data taking with test beam. A member of the group presented to the Collaboration (at the 6th Collaboration Meeting) the first data analysis results, using test beam data collected with SND@LHC.

As had been stated a year ago, objectives within SND@LHC were still materializing and under discussion at the time. This process converged well, and resulted in the achievements described above. These ought to be considered well beyond expectation. And especially so considering absence of funding in the group. In this context, the collaboration with the Mechanical Workshop and the RPC group in particular ought to be duly acknowledged. Support from the Directorate and encouragement from the Advisory Board are also noted.

The involvement of the group in SHiP encompases two lines of activity, namely: (i) detector development, with focus on RPC technology; and (ii) physics studies, with focus on machine learning (ML) methods. The set of well defined plans in these two fronts and the considerable involvement of the group in the SHiP experiment has more recently received a dimmed priority. This is due to the combined circumstance of the effective delay in the SHiP TDR phase and lack of funding for the associated projects. Clearly, these two core fronts of activity are effectively being refocused in the shorter-term to the SND@LHC project, which demands considerable dedication.

Software studies of the optimization of the selection and identification of hidden particles were nonetheless pursued. The continued focus has been in the exploration of ML methods for studying and classifying different FIP signals. These include dark photons, neutralinos, and sterile neutrinos. Multiclass signal classification has been explored with neural networks, following studies of background discrimination. The activity also counted with the involvement of two undergraduate students, who have carried out internships in the group.

Lines of work and objectives for next year

The priority involvement of the group for this year is the SND@LHC experiment. The activity spans commissioning, data taking and physics validation, and detector upgrade. Specific activities in SHiP will be also maintained, and advanced as feasible.

The SND@LHC detector is being installed in its location in the LHC tunnel, in preparation for the start of data taking in the Spring, with LHC Run 3. This is clearly a critical period for the project, with many challenges to overcome, and in a continuing tight schedule. Too detailed planning is, once again, not suitable, in view of the rapidly evolving nature of the project.

Commissioning. Prior to data taking with LHC collisions, baseline integration and commissioning is needed. The various detector subsystems and their readout need to be integrated, aligned and calibrated. Data quality monitoring and ready reconstruction will be implemented.

Physics. Analysis of first data, in addition to beam test data, will be essential to identify and correct potential hardware and software issues. Physics object reconstruction, optimization, and validation will be crucial. The foremost physics goal will be the observation of collider neutrinos. This goal is paramount, as it has not been achieved before, and because it shall provide access to the energy range from 100 GeV to 10 TeV that has not been explored up to here. The first collider neutrino signals at SND should come from the muon neutrino. The achieved performance of the Muon system is naturally here determining.

Upgrade. The accurate monitoring of the muon flux in the SND@LHC experiment is paramount. It would be desirable to have such measurements performed at different angles, and eventually in different locations, in view of future SND upgrades. Our group collaborates with the RPC group and the Detectors Laboratory at LIP, in the design and construction of such an apparatus based on a sealed RPC chamber, towards deployment at the experiment.

The group will remain primarily engaged in the Muon system of SND@LHC, and in the commissioning, operation, validation, and physics exploration with the novel LHC experiment.

Medium-term (3-5 years) prospects

The planned main focus for the next few years is on SND@LHC. The experiment will collect data starting this year and until 2025. The experiment is expected to provide first measurements of collider neutrinos and to search for FIPs in an unexplored domain. The LHC delivers the highest energies yet of human-made neutrinos, and their detection will be a milestone. All three neutrino flavours will be studied, in an unexplored energy domain (from 350 GeV to several TeV).

Larger datasets will allow to carry out heavy flavour studies, in a kinematic range not accessible to the current LHC detectors, and searches for light dark matter. Neutrino based lepton flavour universality (LFU) tests, further relevant in view of the current flavor anomalies in collider data, will become possible.

The group plans to play an active role in the upgrade of the experiment, contributing dedicated detectors based on novel RPC technologies. Upgrades of SND are envisioned also beyond Run 3, possibly involving new detector concepts and locations. A proposal for a future Forward Physics Facility (FPF) at CERN is being discussed. The desire is that of more fully exploring the physics potential of the LHC in the high-luminosity era.

SHiP along with BDF at the SPS will serve as a general-purpose facility for the exploration of FIPs and neutrinos. Here the group has already well established areas of contribution within the collaboration, around the development of timing and veto systems and of physics analysis.

SWOT Analysis

Strengths

The team is formed of consolidated researchers with accumulated expertise in both physics analyses and detector development. Including on the very competitive RPC technology; fixed-target and colliders; heavy flavour physics and hidden-sector searches with long-lived signatures; machine learning. The project demonstrates the ability of consistently attracting students.

Weaknesses

The group has been running without budget. The situation has now changed, with the recent approval of a project for SND@LHC. The resources allocated remain however limited in view of core planned activities.

Threats

Lack of suitable funding and student support. SND@LHC is being built under an aggressive schedule. The timeline of SHiP is currently unclear.

Opportunities

SND@LHC is a new kind of experiment in particle physics and at the LHC. Experiment extends the LHC physics scope and opportunity. SHiP if approved will be a major player in experimental particle physics. Physics case drawing an explosion of interest, potential to bring significant breakthrough to the field.

SHiP

Publications

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

- *"Sensitivity of the SHiP experiment to light dark matter"*, SHiP Collaboration (338 authors), J. High Energy Phys. 4 (2021) 199

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

- *"Sensitivity of the SHiP experiment to dark photons decaying to a pair of charged particles"*, SHiP Collaboration (335 authors), Eur. Phys. J. C 81 (2021) 451

1 Proposal(s) and related studies

- *"SND@LHC - Scattering and Neutrino Detector at the LHC"*, SND@LHC Collaboration, CERN-LHCC-2021-003

1 LIP Students Note(s)

- *"Distinguishing Hidden Sector Particles with Machine Learning at SHiP"*, Henrique Santos, André Branco, LIP-STUDENTS-21-06

Presentations

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

- Andre Branco, Henrique Santos: *"Identifying Hidden Particles with Machine Learning at SHiP"*, 2021-09-13, LIP Internship Program 2021,

Theses

1 Master

- Guilherme Soares: *"Optimization of the Selection of Hidden Particles in the SHiP Experiment"*, 2019-04-01 / 2021-01-25, (finished)

[Detector development for particle and nuclear physics]

RPC

nDet

GasDet

LqXe

RESEARCH / DETECTOR DEVELOPMENT FOR PARTICLE AND NUCLEAR PHYSICS

RPC

Resistive Plate Chambers R&D

Principal Investigator:
Alberto Blanco (55)

7 ***Researcher(s):***
Andrey Morozov (40), Daniel Galaviz (15), Luís Margato (60), Miguel Couceiro (10), Paulo Crespo (25), Paulo Fonte (55), Susete Fetal (10)

7 ***Technician(s):***
Américo Pereira (15), João Saraiva (70), Luís Lopes (32), Nuno Carolino (10), Nuno Filipe Silva Dias (25), Orlando Cunha (9), Rui Alves (9)

1 ***PhD Student(s):***
Ana Luísa Lopes (100)

1 ***Master Student(s):***
Jorge Francisco Silva (14)

Total FTE:
5.5

Articles in international journals: **2** Direct contribution
1 Indirect contribution

Executive summary

2021 has been a succession of approved projects and achievements. In the "Fundo CERN" call, we secured funding to perform fundamental R&D on RPCs, renewing the RPCAdvance (2020-22) project as RPCInnova (2022-24) "Advances in RPC technology targeting experiments at CERN". In the FCT call for funding in all scientific domains (PTDC), the RPC and NUC-RIA LIP groups jointly obtained funding for the installation of a 2 m² RPC to measure the proton time-of-flight in an experiment of the R3B collaboration, SCORE (2022-24) "Short range CORrelations on Exotic nuclei at R3B/FAIR using tRPCs". In collaboration with other LIP groups we are involved in three other new funded projects: "Muography as a new tool for geophysics", "Fast timing high resolution nRPC-4D detector concept for neutron science", and "Participation in the SND/LHC experiment at CERN".

On the achievements side, the HiRezBrainPET tomograph has been fully assembled and is ready for final evaluation, the new time-of-flight detector for HADES has been built and installed, and the first STRATOS station has been fully assembled and delivered to the company HIDRONAV S.A. Unfortunately due to the pandemic situation (and other factors) HIDRONAV has gone bankrupt and its future is uncertain at this moment.

Currently the group activities are focused on the following lines: **RPC-PET** with the R&D and construction of a Human Brain PET, **tRPCs** for the HADES and R3B experiments, development of **PS-RPCs** cosmic ray telescopes, STRATOS (for HIDRONAV) dedicated to the precise measurement of cosmic ray flow, and MUTOM for muon tomography in mines and finally development of **autonomous** RPCS operated at high altitude (SWGO project) and operation of RPCs in an ultra low gas flow regime (eventually sealed). In addition, the group, has a close collaboration with the Neutron Detector group in the development of RPCs for thermal neutron detection. Finally, as mentioned above, the group is now part of the SND collaboration with the main goal (on the hardware side) of developing sealed RPC for the background measurement of the SND environment, a perfect first application for this new technology.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Paulo Fonte		161.255 €	2019-06-17 / 2022-04-16	POCI-01-0247-FEDER-039808 / HiRezBrainPET: high resolution positron emission tomography (PET) neurofunctional brain imaging (consortium led by ICNAS produção)
Alberto Blanco		70.000 €	2020-07-01 / 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 / 2025-03-31	101004761 AIDAinnova / AIDAinnova
Alberto Blanco	Paulo Fonte	70.000 €	2022-07-01 / 2024-06-30	CERN/FIS-INS/0006/2021 / RPCInnova - Avanços na tecnologia de RPCs visando experiências no CERN

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 (CERN) 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, which are and will remain present in many high-energy physics experiments (ALICE, BESIII, BGO-EGG, CBM, FOPI, HADES, HARP, STAR).

Besides the original work in ALICE, along with numerous international and local collaborators, we contributed to the field with developments that expanded the RPC applications range, continuing to work on some of these lines: very large area/channel tRPCs, shielded tRPCs for robust multi-hit capability in dense arrays (HADES), the 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 development of technology-expanding devices, we keep an interest in RPC's physical modelling and other fundamental issues, such as gas mixture properties and ageing.

The group have three main lines of work: 1) PET, 2) TOF & TOF-Tracking, and 3) autonomous RPCs for cosmic ray measurements.

1) The **RPC-PET** technology has already been successfully applied in pre-clinical PET, where it reached or exceed the target spatial resolution. It has the potential to be applied in human brain PET changing 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. Furthermore, a full body human PET system with an extension of 2.4 meters, allowing for a PET scan to cover the entire patient within a single-bed acquisition, would increase the system 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 provided only in the centre of the field of view of commercial tomographs. Responsible: P. Fonte.

2) **Timing RPCs (tRPCs)** continue to be one of the main technologies for the identification of particles (using the time of flight technique) in high energy physics experiments when large areas are needed. The precise measurement of the particle position (**Position Sensitive PS-tRPCs**) simultaneously with time 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 modalities, transmission (e.g. volcano and mine imaging) and scatter tomography (container scanning) are of interest for the group. Responsible: 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. Responsible: L. Lopes.

In addition to this main activities the group is also involved in the development of High-rate RPCs and Epi-thermal neutron position-sensitive RPC (see specific report from the Neutron Detectors group).

Assessment of the past year: objectives vs. achievements

Objectives for 2021 as stated in the 2020/2021 report and plan:

- Production and evaluation of the final four-heads HiRezBrainPET system.
- Construction and validation of the three remaining modules of the RPC-TOF-FD for the HADES group.
- Continue supporting the TRISTAN operation (although for 2021 the polar campaign has been drasticaly reduced due to the pandemic situation) and the data analysis now in collaboration with our colleagues at University of Santiago de Compostela (USC).
- Complete the full integration of the MUTOM telescope (sealed box for the DAQ components), investigate and solve the problems encountered in the DAQ and start field operation if the pandemic situation allows it.
- Complete characterization (including efficiency measurement) of RPCs operating in a pressure range from 1000 to 400 mBar with different gap number/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.
- Construction of new sealed RPC chambers with larger areas. A full instrumented four plane (1x1 m²) telescope will be produce and tested along the year as a proof of concept.
- Consolidate the tasks proposed in the RPCADVACE project.
- Complete the evaluation of the first STRATOS module and finalize the construction of the remaining 7 modules.
- Start the execution of the AIDAInnova project (in this moment the timeline of the project is not yet know).

Achievements

All components of the **HiRezBrainPET** have been built. They were mostly designed by (or with a major contribution from) the LIP group, with the full support of LIP's Mechanical Workshop and Detectors Laboratory. The main parts are: individual head mechanics and head support structure, 300x300 mm² five gap RPC detectors, signal pickup electrodes and interface PCBs, charge and time amplifiers, digital data acquisition system, low and high voltage power supplies, I2C based control system and gas distribution system. The system has been fully assembled and is ready to start performance evaluation tests. As a reference, the system were tested with cosmic rays showing a spatial precision well below 100 us and a timing precision better than 200 ps, perfectly suitable for a Brain PET tomograph.

The construction and testing (with cosmic rays) of the second and third **RPC-TOF-FD** sectors for the **HADES** group were completed before the end of the year. The fifth (spare) sector has not yet been assembled, but most of the parts are already produced. See HADES group report for more information.

Due to the pandemic situation, the **TRISTAN** detector at the Antarctic base remained inoperative. The project supporting this action has ended and TRISTAN is expected to return to Spain during 2022. Except for publications and the completion of a USC student PhD thesis , it is not expected that activities related to this project will continue. At the moment it is not clear what the future of TRISTAN will be.

The **MUTOM** telescope (a four plane MARTA-like RPC telescope equipped with low power consumption electronics, MAROC boards, capable of operating with solar panels) was fully integrated at the beginning of the year. The problems detected in the DAQ (loss of events) were diagnosed and fixed with the help of a new team member, Jorge Silva, during the LIP summer Internship. The field operation started at the end of the year by muographing several parts of the Physics Department in Coimbra. See MUTOM group report for more information.

The complete characterization of the MARTA-like RPCs for the **SWGO** project was not done, due to lack of available time and human resources. This topic is a high priority for 2022. The development of **Sealed RPC** is in the same situation, with high priority for 2022. This last topic is part of the recently approved RPCInnova project (2022-2024).

The execution of the **RPCAdvance** project is well ahead (ending in July 2022). The following four topics have been addressed in this project.

1. *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 for blocking external agents (atmospheric gases or water vapour). These detectors are able to operate stably with gas flow rates of ~1 cc/min/m², improving by a factor of two our previous result in this area.
2. *Position sensitive timing RPCs:* we have built a 0.1 m² prototype with a position and timing precision of 60 um and 160 ps (the latter we expect to improve). These results are consistent with our previous result but over an area 10 times larger.
3. *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 20 to 40) increases the count rate by a factor of 4 (from 0.4 to 1.4 kHz), while maintaining efficiency (92 %) and time precision (100 ps). We are also testing a new low resistivity glass from PICOTech SAS with a promising resistivity of 1.10^{9}.
4. *Neutron detector based on ^{10}B* converter: combining all the results obtained in the other topics we are building a new neutron detector optimized for high rate, which will be tested in spring 2022.

Although **STRATOS** accumulated a considerable delay in 2020, during 2021, due to the extraordinary effort of the Detectors Laboratory, the first station (a four-plane telescope) was fully assembled. Each plane (2 m²) exhibits a homogeneous efficiency of around 98% together with a 2D spatial precision better than 1 cm and an industrial design that facilitate enormously the deployment (planes consist of a closed box that only need communications, gas and power to be operated). This first unit was transferred to the company and is now operational in Spain. The second station is almost fully assembled and is expected to be finished and delivered in 2022.

We have started to work on the **AIDAInnova** project with the evaluation and testing of a new low resistivity glass (topic that overlaps with the RPCAdvance project).

Although this activity was not planned, due to the recent approval of the SCORE project, a 2 m² RPC with an efficiency higher than 98% and a time precision better than 50 ps has been installed in the target hall of the **R3B** experiment at GSI and is currently in the calibration phase. This detector is the prototype developed for SHiP, which will not be used at CERN for the time being. This is a great opportunity to finalize the development of the detector, with commissioning, calibration and data analysis during the experiment planned for spring 2022.

Lines of work and objectives for next year

The objectives for 2022 can be summarised as follow:

- Evaluation and first human test of the full **HiRezBrainPET** system.
- Construction and validation of the spare sector of the **RPC-TOF-FD** for the **HADES** group.

- **MUTOM** operation in the field (inside the Lousal mine and at other possible sites), which should start in the spring.
- Complete characterization (including efficiency measurement) of RPCs operated in a pressure range from 1000 to 400 mBar with different gap number/widths for the **SWGO** project. The test will be performed with the MAROC board to obtain a complete characterization of the system at equivalent altitudes.
- Construction of new **sealed RPC** chambers with larger areas. A fully instrumented four-plane (1x1 m²) telescope will be produce and tested along the year as a proof-of-concept.
- Finalize the tasks proposed in the **RPCAdvance** project and start the following project, **RPCInnova**, focused on ultra-low gas consumption and position-sensitive timing RPCs.
- Finalize the integration of the final **STRATOS** station.
- Continue execution of the **AIDAInnova** project.
- Operation, calibration and data analysis of the proton TOF detector within the **R3B** collaboration.

Medium-term (3-5 years) prospects

As part of our R&D line in RPC-PET, we will finalize the R&D and construction of the Brain PET and the upgrade of the existing RPC-PET to a pre-commercial small-animal scanner, and continue supporting the PET examinations at ICNAS. Afterwards, the consolidation of the knowledge gained in these two projects will be necessary to be able to offer a final/commercial product.

Included in our R&D line of TOF-RPCs and PS-tRPCs, in the short-term, the new RPC-TOF-FD for the HADES experiment will be put into operation. 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. The short-term plan is to use the detector in a single experiment, but our mid-term plan is to have a permanent detector to be used in all the experiments where it might be needed. On the other hand, the STRATOS detector will be finished in the short-term, but unfortunately the collaboration with the company HIDRONAV no longer seems possible due to its current situation. We will continue learning with the new MUTOM telescope, objectives that are mixed with the autonomous RPC line.

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 flow (eventually sealed). In this context, the project approved by "Fundo CERN", RPCAdvance and RPCInnova, will be fundamental to advance in this matter and others included in the project, such as the development of the simultaneous measurement of position and time.

Finally, the group wants to attract students (something that has not been very common in the past).

SWOT Analysis

Strengths

- The team has proven repeatedly to be competent, inventive, productive and reliable. We have access to LIP's technical infrastructures, which include some very good and experienced technicians and a well equipped Mechanical Workshop.

Weaknesses

- The rather small size of the team and their dispersion among many projects. Recruitment of students or other senior member will help.

Opportunities

- We believe to have, or to be about to have, very competitive detectors for the market of applications: animal and human RPC-PET, muon tomography, cosmic-ray physics and HEP.
- The full-body human 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 funding obtained in the "Fundo CERN" call will boost fundamental R&D.

Threats

- Non stable funding environment. We complained in the past about little funding, now we are complaining about a lot ... but it seems that we are stabilizing. FCT is now committed to open regular calls, which is very helpful.
- In the long term, the excessive maturation of the team members will become a determinant factor. Students would contribute to mitigate this.

RPC

Publications

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

- *"Towards high-rate RPC-based thermal neutron detectors using low-resistivity electrodes"*, L.M.S. Margato, A. Morozov, A. Blanco, P. Fonte, L. Lopes, J. Saraiva, K. Zeitelhack, R. Hall-Wilton, C. Höglund, L. Robinson, P. Svensson, L. Naumann, K. Roemer, D. Stach and Th. Wilpert, L.M.S. Margato et al 2021 JINST 16 P07009
- *"Statistical position reconstruction for RPC-based thermal neutron detectors"*, A. Morozov, L.M.S. Margato, V. Solovov, A. Blanco, J. Saraiva, T. Wilpert, K. Zeitelhack, K. Roemer, C. Höglund, L. Robinson and R. Hall-Wilton, A. Morozov et al 2021 JINST 16 P08032

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

- *"The TRASGO Project. Present Status and Results"*, D. Garcia-Castro et al. (27 authors), Phys. Atom. Nuclei 84 (2021) 1070-1079

Theses

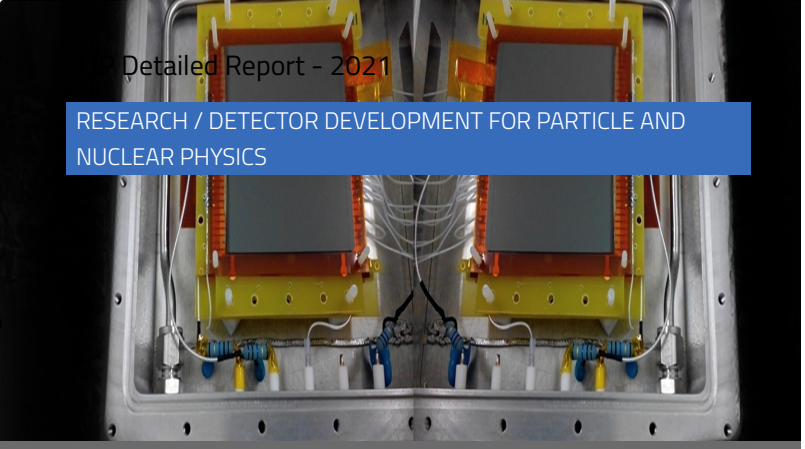
1 PhD

- Ana Luísa Lopes: *"Study by simulation and reconstruction of a brain-dedicated positron emission tomograph based on resistive plate chambers"*, 2017-10-02 , (ongoing)

1 Master

- Jorge Francisco Silva: *"(Title to be defined)"*, 2021-11-08 , (ongoing)

RESEARCH / DETECTOR DEVELOPMENT FOR PARTICLE AND NUCLEAR PHYSICS



NDET

Neutron detectors

Principal Investigator:
Luís Margato (40)

3 ***Researcher(s):***
Alberto Blanco (5), Andrey Morozov (30), Paulo Fonte (10)

3 ***Undergraduated Student(s) and Trainee(s):***
Gonçalo Gomes, Inês Serra, Mariana Santos

1 ***External collaborator(s):***
Alessio Mangiarotti

Total FTE:
0.9

Articles in international journals:	**2** Direct contribution
Notes:	**1** LIP Students note
International conferences:	**1** Oral presentation
Advanced Training Events:	**1** Student presentation

Executive summary

The Neutron Detectors group focuses on the development of detectors for neutron scattering science applications and has contributed innovative ideas to the field. We have introduced a novel neutron detection technology based on a combination of B_4C solid neutron converters and resistive plate chambers (RPC). The first stages of the development were conducted in the frame of the SINE2020 collaboration in partnership with the teams from ESS and FRMII demonstrating that this is a promising technology. We have also participated in the detector R&D programmes of several successive European projects (NMI3-FP6, NMI3-FP7 and SINE2020-H2020) in collaboration with the world leaders in the field such as ILL, ISIS, FRMII and ESS neutron facilities.

Neutron detectors are the key tools in neutron scattering science, which, in turn, plays a crucial role in both fundamental and applied research in areas such as physics, chemistry, biology, medicine and engineering. The importance of neutron science for society is recognized by the EU which has invested 2 billion euros in the ongoing construction of the next generation neutron facility, the European Spallation Source (ESS), one of the world's largest scientific and technological infrastructures being currently built. However, it is broadly acknowledged that the present state-of-the-art detectors cannot fully satisfy the demanding requirements of the next generation instruments planned for the ESS and the future spallation sources, as well as of the upgrade programs of the existing neutron facilities.

The main priority of the group is to progress with the development of the ^{10}B-RPC detection technology for high precision and high counting rate position sensitive detectors for cold and thermal neutrons, foreseeing its application in, e.g., TOF small-angle neutron scattering (SANS), reflectometry, macromolecular crystallography and MIEZE neutron spin-echo spectroscopy. The MIEZE technique is especially interesting for us as it requires a demanding combination of the detector properties (response time below 1 μs, very well-defined detection planes and high spatial resolution) which is feasible to achieve with RPC-based neutron detectors, and is not easily accessible with the competing detection technologies.

Currently the group is working on the construction of a prototype of a ^{10}B-RPC detector in the framework of the FCT-funded RPCADVANCE project. This work is performed in collaboration with the RPC R&D group. The main objective is to prove the capability of our neutron detection technology to offer high counting rate capability: the prototype should be able to handle local counting rates of the order of 100 kHz/cm^2.

The group is also investigating the possibility of applying the ^{10}B-RPC technology for detection of fast neutrons with a broad energy spectrum in the range from a few keV up to ~ 5 MeV. Such detectors are needed, e.g., for the measurements of the beta delayed neutron emission probabilities for very exotic nuclei. Several detector concepts were developed, optimized and characterized in detailed simulations performed jointly with the NUC-RIA and RPC R&D groups. A paper with the main findings has been prepared for submission to a peer-reviewed journal.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Alberto Blanco		70.000 €	2020-01-01 / 2021-12-31	CERN-FIS-INS-0009-2019 / RPCADVANCE : Advancement of the RPC detector technology targeting CERN experiments and applications for society
Luís Margato	Andrey Morozov	49.957 €	2022-01-01 / 2023-06-30	EXPL/FIS-NUC/0538/2021 / Fast timing high resolution nRPC-4D detector concept for neutron science

nDet

Overview

The group aims to contribute to the research and development of advanced neutron detection technologies, and their applications in neutron scattering science, mainly within the scope of the large-scale detector R&D programmes in partnership with the world's leading neutron facilities such as ILL, ISIS, FRMII and ESS. The group's R&D activities rely on its members' extensive expertise in detectors for particle and nuclear physics, MC simulations (GEANT4 and ANTS2), event position reconstruction techniques, design and implementation of complete detector systems and detector characterization at the neutron beamlines of large-scale facilities. The team is composed by four researchers and a student: Luís Margato (group coordinator), Andrey Morozov (Monte Carlo simulations and event position reconstruction techniques), Alberto Blanco (RPC detectors), Paulo Fonte (RPC detectors) and Inês Serra (Physics Engineering student). The group has also a strong synergy with the activities conducted in the RPC R&D Group at LIP. Currently we are working along two research lines:

Development of ^{10}B-RPCs thermal neutron detectors

The goal is to improve the performance of the ^{10}B-RPC detectors in terms of the detection efficiency, gamma sensitivity, counting rate capability, time and spatial resolution in order to meet the strict requirements of the neutron scattering applications at the large-scale facilities (LSF) in general, and, in particular, at ESS. The work is conducted focusing on the following tasks,

- *Improvement of the ^{10}B-RPC counting rate capability*

  It includes the tests of new materials with bulk resistivity in the range 10^9-10^{10} Ω·cm, development of novel detector designs based on multilayer and jalousie architectures, Monte Carlo simulation studies targeting the design optimization and work on the data acquisition and analysis tools.

- *Reaching higher spatial resolution*

  The main activity of this task is the optimization of the signal readout and implementation of new event position reconstruction techniques, namely based on statistical methods. There is the potential to reach position resolution of ~0.1 mm, unlocking new opportunities in the neutron science applications.

- *Decreasing the backgrounds*

  For detectors utilized in neutron scattering applications an excellent signal-to-background ratio is a crucial factor to deliver high-quality scientific results. However, neutron detectors often have to operate in an environment with strong gamma background, and gamma sensitivity of the detectors has to be reduced as much as possible. On the other hand, the RPC operation can result in some intrinsic background which also has to be decreased as much as possible. Our work involves simulation-based optimization of the detector components as well as basic research since the scientific understanding of the operation of RPCs as neutron detectors and the origin of dark counts in RPCs is still very limited.

Fast neutron detector for β-delayed neutron emission experiments

We are continuing our investigation of the applicability of the ^{10}B-RPC technology for building detectors for fast neutrons with a broad energy spectrum ranging from a few keV up to 5 MeV. Such detectors are needed for the measurements of the beta delayed neutron emission probability from very exotic nuclei. For these experiments they should provide good (~50%) detection efficiency with a flat response up to the neutron energy of at least 2 MeV, which, as we have demonstrated during this year, is feasible. The next major objective is to perform accurate measurements of the dark count rate with a small-scale prototype. It is expected that the rate will be higher than demonstrated by the gold standard detection technologies applied in that field. Therefore, we plan to find and implement strategies to reduce the dark count rate.

Assessment of the past year: objectives vs. achievements

The first and main objective for 2021 was:

To design, optimize and construct a prototype of a ^{10}B-RPC detector in the framework of the FCT-funded RPCADVANCE project.

Regarding the prototype design and MC simulation-based optimization, all proposed goals for this year were achieved, namely:

- Design of the detector chamber and of all its components is completed.
- Structure of the double-gap ^{10}B-RPCs units and of the signal pickup strips pattern is established.
- Design of the printed circuit boards (PCBs) to hold the FEE and connect them to the DAQ, and of the flexible printed circuits (FPCs) to connect the 4224 pickup strips of the detector to the front-end electronics (FEE) are completed.
- Optimization of the converter layers thickness for the prototype with 10 double-gap RPCs, having a total of 20 layers of B_4C enriched in ^{10}B (97% enrichment level) was performed. The simulations were conducted with GEANT4 v10.7.2 with QGSP-BIC-HP physics list and ANTS2 v4.36 as the frontend. The layer thickness optimization followed the procedure described in “A. Morozov et al 2020 JINST15 P03019”.

Materials for the construction of the double gap ^{10}B-RPCs were selected and already acquired. The selection was subjected to an evaluation taking into account parameters such as, e.g., neutron activation, neutron scattering and absorption, thickness and robustness, scalability to large areas and commercial availability:

- Despite its high resistivity (~ 5 x 10^{12} Ω.cm), we have chosen 0.3 mm thick float glass for the anode plates due the fact that they have excellent homogeneity, good surface smoothness, the thermal neutron absorption and scattering are at an acceptable level and they are commercially available with large areas.
- For the cathodes, 0.3 mm thick sheets of the aluminium alloy 5754 have been chosen due to their high strength and relatively low neutron absorption and scattering when compared with the other available alloys.
- To define a very thin gas-gap width, a 0.28 diameter PEEK monofilament was chosen instead of the nylon used in the previous prototype due to its better dimensional stability.

On the detector components manufacturing:

- Machining of the aluminium cathode plates in the required shape and their polishing in the LIP Mechanical Workshop has been carried out.
- The plates were sent to the Detector Group of the European Spallation Source (our collaboration partner) to be coated with the $^{10}B_4C$ neutron converters, which is one of the most critical elements of the detector to be built.
- The coatings were successfully manufactured. Several challenges had to be addressed: keep the Al-cathode plates flat; guarantee sufficient uniformity in the thickness of the $^{10}B_4C$ coatings over the entire area (200 mm x 200 mm) and produce 3 different thicknesses. In all the 0.3 mm thick Al cathode plates that have been coated no adhesion issues or bending were observed.
- First glass plates (200 mm x 200 mm) were coated with a ~2 μm thick layer of Al on one side, by rf-sputtering at IPN Coimbra (Instituto Pedro Nunes). Several tests were performed to etch the strip array pattern by photolithography, however etching of Al with the acid solution was found to take too long time (~1h), leading to the loss of adhesion of the negative dry-film photoresist in some areas, which, in turn, results in irregularities in the produced strips. Also, the Al coatings exhibit a whitish colour on the surface in contact with air, revealing the formation of aluminium oxides. We have found that the Al oxides are protecting the coating from the chemicals, hampering the etching process. Considering these results, it was decided to switch to copper coatings (much more straightforward to etch) despite higher neutron absorption and scattering cross sections compared to aluminium. First validation tests have already been performed. Coating of the detector's glass plates with cooper is scheduled for January/February 2022.
- The manufacturing of the detector's chamber is to be performed by the Mechanical Workshop of LIP together with the Detectors Laboratory. There were some unexpected delays but the production has already started.
- FEE and the DAQ systems for signal acquisition are already being prepared by the RPC R&D Group.

The severity of the pandemic situation during 2021 has led to significant delays in the procurement and production of several detector components. However, all issues are solved and construction can start in early 2022.

Two papers were published by the group in a peer-reviewed journal.

The second objective for 2021 was:

To investigate the capabilities of applications of ^{10}B-RPCs for the characterization of the delayed neutron emission probability in very exotic nuclei beta decay experiments.

This objective was fully achieved. A comprehensive simulation study was conducted, establishing several possible conceptual designs of the detector. The performance of different configurations was cross-compared in terms of the detection efficiency, the response flatness and the required total area of the RPCs. The detector models were developed in the ANTS2 package and a series of detailed simulations was conducted with GEANT4. Based on the obtained results, the best design of the detector was selected, optimized and the expected performance fully characterized.

At the next step the predicted performance was compared with the results available for the gold standard ^{3}He-based detectors currently applied in the targeted experiments. We have shown that we can offer a detection efficiency and flatness quite similar to the ones of the best fast neutron detector for delayed neutron emission experiments operating nowadays, while the overall detector price can be reduced by an order of magnitude.

We have also found that in the operation conditions required for these experiments the dark count rate of ^{10}B-RPCs detectors is an order of magnitude higher compared to the ^{3}He-based detectors. Note that for the thermal neutron detectors developed in our group this parameter always had a negligible effect, therefore a new experimental direction has to be initiated dedicated to the characterization, investigation of the mechanism and, finally, to the reduction of the dark count rate.

A paper summarizing the main results has been prepared and submitted for publication in a peer-reviewed journal in collaboration with the NUC-RIA Group.

In addition to the planned activities, we have also performed an evaluation of a very recently introduced low resistivity glass, which show attractive properties for ^{10}B-RPCs.

Motivated by one of our primary objectives (increase of the counting rate capability of ^{10}B-RPCs), a novel low resistivity glass from Picotech SAS has been tested. The samples (0.4 mm thick glasses with an area of 6 cm x 6 cm) were provided by Crispin Williams in the frame of a new collaboration. It should be noted that one of the most promising directions to greatly improve the count rate capability of RPC-based detectors is to make electrodes from materials with much lower resistivity than that of the currently used float glass. Although this has been the subject of several studies, well documented in the literature, the problem of obtaining a material with adequate resistivity, showing good homogeneity and available in small thicknesses and in large areas has not been solved yet.

The Picotech glass resistivity was studied using an argon discharge method, and an electrical bulk resistivity of ~1.5 x 10^9 Ω.cm was measured at room temperature (22ºC), which is significantly lower than that of the float glass (~5 x 10^{12} Ω.cm). We also left the detector operating until an integrated charge of ~ 0.5 C/cm^2 was reached, which corresponds to ~ 60 days of continuous RPC operation in an avalanche regime at a count rate of 100 kHz/cm^2. Then, the repeated measurements have shown a resistivity of ~ 4.3 x10^9 Ω.cm, revealing an increase with the integrated charge. Nevertheless, the resistivity of the Picotech glass is still about 3 orders of magnitude lower than that of the float glass. Moreover, preliminary results show evidence that by reversing the polarity of the voltage applied to the RPC, the resistivity of the Picotech glass recovers to a value close to the initial one. This behaviour still needs a detailed study, however it suggests that there is a possibility of using polarity reversal to restore the glass resistivity, which is a quite feasible approach considering operation conditions of the thermal neutron detectors at the large scale facilities.

With a resistivity about 3 orders of magnitude lower than that of the float glass, a much higher count rate capability (>100 kHz/cm^2 for a single RPC) is to be expected for ^{10}B-RPCs constructed using this glass. However, long-term studies on the stability, radiation effects and aging are still to be performed.

Internships

As a part of the LIP Internship Program 2021, the Neutron Detectors group hosted 3 students (Gonçalo Gomes from the University of Porto, Mariana Oliveira and Inês Serra from the University of Coimbra). The students participated in the assembly of an RPC detector with electrodes made of a new low resistivity glass and in the characterization of its resistivity. The students were also introduced to MC simulations and published their achievements in an internal note, publicly available on the LIP website.

Attracting students

A call for a research initiation student fellowship (BII) was launched in the frame of the RPCADAVANCE project. Inês Serra was the selected candidate and she has joined the Neutron Detectors group. The group has also prepared research proposals for the Portugal-CERN PhD Grant Programme 2021, and the call for grants for MSc in Physics Engineering at the Department of Physics of the University of Coimbra, but there were no candidates.

Funding

The group prepared and submitted a proposal (EXPL/FIS-NUC/0538 /2021) to the PTDC-2021 call from FCT. The project was selected for funding and the evaluation panel commented "The envisaged detector, once successfully realized, will open a whole new range of applications in neutron-based science and thus indirectly will certainly contribute to the advancement of knowledge in many different fields". The project focuses on the development of a fast-timing high resolution nRPC-4D detector concept for neutron science. The detector will be capable to provide an accurate time-of-flight information of the detection events together with the 3D spatial coordinates.

Lines of work and objectives for next year

The group's research activities in 2022 will be organized along two main lines.

The first one is the completion of the construction of the detector proposed in the FCT-funded RPCADVANCE project and carrying out its characterization at a neutron beamline. This activity is to be developed in collaboration with the RPC R&D Group. The tests to fine-tune the detector are to be conducted in LIP and the following characterization of the detector will be performed on a beamline of FRMII (Germany). However, the tests at FRMII may be delayed due to the constraints related to the pandemics.

The second research line is to start the work planned in the project "Fast timing high resolution nRPC-4D detector concept for neutron science" funded by FCT (EXPL/FIS-NUC/0538/202), which is organized as follows:

- **MC simulations and optimization**

  The first objective of this task is to provide a simulation and optimization platform for this project. The second objective of the task is to define the optimal configuration of the detector aiming at the ns-scale timing resolution, spatial resolution of ~0.1 mm, >50% detection efficiency, low gamma sensitivity (< 1 x 10^{-6}) and as low as possible background due to neutron elastic scattering.

- **Development of event reconstruction methods**

  The main objectives are the development and implementation of two position reconstruction techniques for that detector: a quasi-linear centroid reconstruction and a bias-free position reconstruction with a possibility of a calibration from flood irradiation data.

- **Detector demonstrator development and characterization**

  A nRPC-4D detector consists of a stack of B_4C coated t-RPCs units which are the basic building blocks. The fast-electronic component of the signals from each cathode, sensed by fast amplifiers will be used to measure TOF with high precision, benefiting from fast timing of the t-RPCs and the short (~1 ns) flight time of thermal neutrons through ~1 μm thick layers of B_4C. The signals from the cathodes will also be used to identify the neutron capture plane (Z coordinate). The arrays of signal pickup strips facing the outer surface of the resistive anode plates will be used for the readout of the X and Y coordinates of the capture event in the plane of detection.

  We will start work by constructing several basic detection units which are required for validation of the simulations (task 1) and the reconstruction techniques (task 2). We plan to test very narrow gas gaps (0.1 – 0.2 mm) in order to minimize the influence of the ionization tracks on the spatial resolution.

  In the second stage, based on the experimental results obtained previously and the results of the simulation-based detector optimization (task 1), we will start the construction of a small-scale proof-of-concept nRPC-4D detector demonstrator.

Medium-term (3-5 years) prospects

For the next 5 years, motivated by the requirements from the large-scale neutron facilities on the future neutron science instruments, we define our strategy along the following lines:

- Dedicate R&D efforts for the advancement of the ^{10}B-RPC technology in order to be able to reach with the same detector the spatial resolution of about 0.1 mm FWHM, the counting rate capability beyond 100 kHz/cm^2 and provide TOF capabilities. The main objective is to meet the detector requirements for the next generation of TOF diffractometers and reflectometers at the spallation sources.
- Based on the results obtained in the experimental campaigns planned in the near future with the detector demonstrators built in LIP and tested on the neutron beamlines of large-scale neutron facilities (ILL, ISIS, FRM II, and, in the future, ESS), define the concrete neutron science instruments for application of our technology.
- Continue our recently started efforts to promote the possibility of building fast neutron detectors using the ^{10}B-RPCs technology. In particular, we plan to focus on the instruments for the measurements of the probability of the beta delayed neutron emission from very exotic nuclei (e.g. in ISOLDE at CERN). An experimental validation campaign will be planned and realised jointly with the NUC-RIA and RPC R&D groups.
- We plan to further extend our collaborations with the detector groups from the world-leading neutron facilities. As an example of a lucrative possibility, we have recently been invited by Prof. Dr. Florian Piegsa from the University of Bern to perform a test with a ^{10}B-RPC prototype at PSI (Paul Scherrer Institute) to evaluate its potential application for nEDM (neutron electric dipole moment) experiments.

SWOT Analysis

Strengths

Group with an extensive knowledge of the detector physics and experience in the development of neutron detectors.

Strong background in simulation of particle detectors and in the development and optimization of position reconstruction techniques for particle detectors.

Long-standing collaboration with international partners from world-leading large scale neutron facilities, which provides access to neutron beams.

Weaknesses

Limited human resources. Difficulty in attracting young researchers (PhD students and postdocs) due to lack of funding.

Opportunities

Our ^{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.

The international recognition of the group is growing. Recently we were invited to test a ^{10}B-RPC detector at PSI. The detector group from ISIS muon and neutron source (Oxford, UK) proposed to evaluate ^{10}B-RPCs for future applications at their facility.

Threats

Persistence of restrictions and delays in accessing neutron beamlines at large-scale facilities due to the pandemic threaten planned experimental campaigns which are crucial for our R&D activities. No sustainable funding.

nDet

Publications

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

- *"Towards high-rate RPC-based thermal neutron detectors using low-resistivity electrodes"*, L.M.S. Margato, A. Morozov, A. Blanco, P. Fonte, L. Lopes, J. Saraiva, K. Zeitelhack, R. Hall-Wilton, C. Höglund, L. Robinson, P. Svensson, L. Naumann, K. Roemer, D. Stach and Th. Wilpert, L.M.S. Margato et al 2021 JINST 16 P07009
- *"Statistical position reconstruction for RPC-based thermal neutron detectors"*, A. Morozov, L.M.S. Margato, V. Solovov, A. Blanco, J. Saraiva, T. Wilpert, K. Zeitelhack, K. Roemer, C. Höglund, L. Robinson and R. Hall-Wilton, A. Morozov et al 2021 JINST 16 P08032

1 LIP Students Note(s)

- *"Development of a new neutron detection technology"*, Gonçalo Laires Gomes, Mariana Oliveira and Inês Serra, LIP-STUDENTS-21-34

Presentations

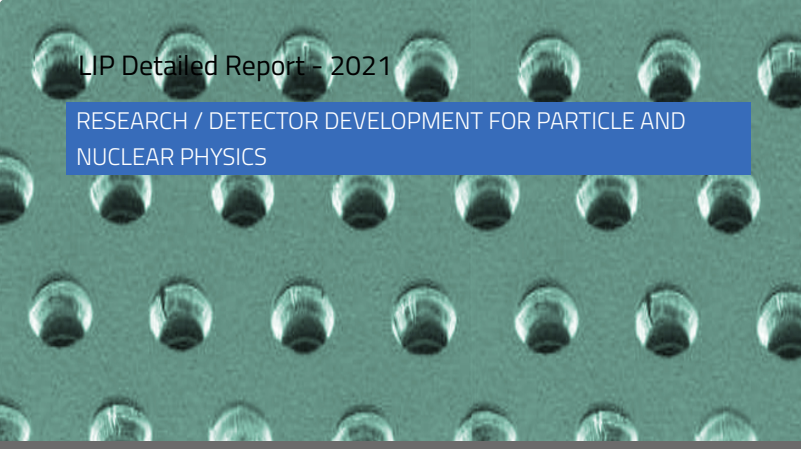
1 Oral presentation(s) in international conference(s)

- Luís Margato, A. Morozov and A. Blanco: *"Development of position-sensitive thermal neutron detectors combining Resistive Plate Chambers and 10B4C converters"*, 2021-08-30, International Atomic Energy Agency (IAEA) Virtual Technical Meeting on Advances in Neutron Detectors for Neutron Scattering and Imaging Applications, Vienna, Austria

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

- Gonçalo Gomes et al, Inês Serra, Mariana Santos: *"Desenvolvimento de uma nova tecnologia para detetores de neutrões"*, 2021-09-14, LIP Internship Program 2021,

RESEARCH / DETECTOR DEVELOPMENT FOR PARTICLE AND NUCLEAR PHYSICS



GASDET

Gaseous Detectors R&D

Principal Investigator:
Filomena Santos (60)

6 ***Researcher(s):***
Carlos Conde (30), Filipa Borges (60), Jorge Maia (15), José Escada (60), João Barata (5), Teresa Dias (30)

2 ***PhD Student(s):***
Afonso Paixão Marques (100), Alexandre Fonseca Trindade (40)

1 ***Undergraduated Student(s) and Trainee(s):***
João Teles

1 ***External collaborator(s):***
David Marques

Total FTE:
4

Articles in international journals: **4** Indirect contribution

Executive summary

The Gaseous Detectors R&D Group does 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 used, in parallel with prototypes of gas detectors and experimental systems adequate for the measurement of relevant quantities developed by the group.

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 can be a strong drawback, since the spatial accumulation of charge can change the electric field and the amplification gain, and so the information on how quickly ions drift from their formation point is an important issue in gas detectors.

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 application. 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 time of arrival at the anode of the different anions. For these reasons the measurement of negative ion mobilities is a novel interest and very important issue. The study of other parameters in these electronegative mixtures, such as the attachment and dettachment efficiency of electrons to electronegative molecules, and possible signal amplification mechanisms in gaseous detectors with these mixtures, is also a study item for the group.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Filipa Borges		62.910 €	2022-01-01 / 2024-12-31	PTDC/FIS-NUC/3933/2021 / NEXT: Detection of the neutrinoless Double Beta Decay in Xe-136-the NEXT experiment (collaboration with LIPPhys, PI Joaquim Santos)

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.

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 as and we now have a reliable and consistent system, providing results that are in accordance with those published in the literature. Measurements have been performed with electronegative dopants. A paper has been accepted for publication in JINST.

Within the scope of the NEXT Collaboration, tests have been made, as planned, to check if the spurious pulses observed in the NEXT electroluminescence TPCs (and indeed in other double-phase dark matter experiments and high pressure xenon TPCs) came from photoelectrons released from the wavelength shifter normally used in these chambers, TPB. Using the prototype previously developed, and within the conditions of our study, no electrons were found that could be linked to the TPB deposit.

Results for electron drift parameters for xenon and for CH4 have been obtained and compared. The choice of these gases was based on the abundance of reliable data available in the literature and the difference in drift behavior they exhibit: xenon has high electron diffusion while CH4 has low diffusion. This difference in behavior was quite noticeable in the results and consistent with other results available. The system has proven its capability and we are now able to 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 energy ranges).

Lines of work and objectives for next year

During the year 2022 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, as usually, we will try to answer, interpret and explain unexpected issues that keep arising in the cutting edge and demanding conditions of the experiment. Also, with the new available device, electron diffusion coefficients will be measure for the mixtures considered of for the experiment.

Having assessed the validity of the results obtained with our diffusion measuring device we will proceed to measurements in gases for which 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 energy ranges).

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 investigation. This is quite a novel field in spite of the fact that several successful applications of negative charge carriers have been reported. Nevertheless a consistent study of the properties of these mixtures in its different parameters, which 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 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 will develop 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 electronegative dopants in detection gases. This is a field that may be explored and originate further collaborations with groups that are interested in this area that 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.

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.

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 5 years will also depend on issues that will arise in the collaborations we integrate, namely the assembly and first tests with the 100 kg TPC in NEXT, and also on the available funding and human resources that have been very uncertain in the last years.

SWOT Analysis

Strengths and Opportunities

The group has had the capability to atract students (9 thesis, master or PhD, and a few summer internships in the last three years). This has been possible due to the experimental systems that are working and are supervised by Alexandre Trindade (at the moment a PhD student that is about to finish his thesis) and due to the simulation work developed by the team.

Weaknesses and Threats

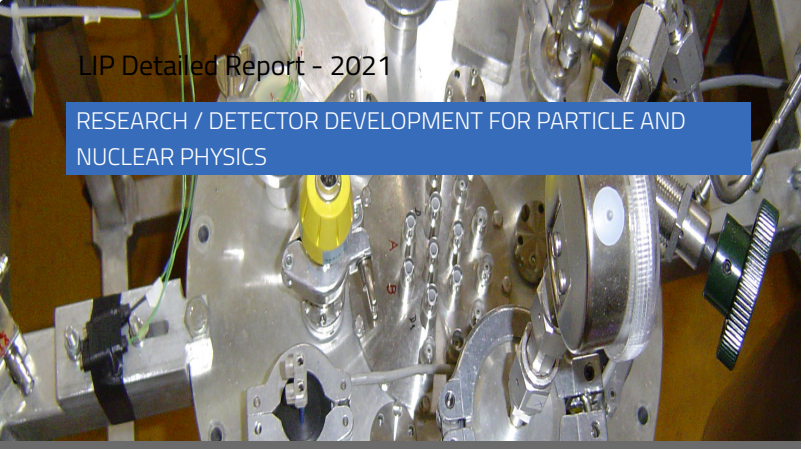
The lack of funding will result in the near future in the loss of a fundamental member of our team, that has been responsible for the laboratory work, the supervision of the new students, and that has been with the LIP group for more than 10 years now.

Publications

- *"Demonstration of background rejection using deep convolutional neural networks in the NEXT experiment"*, NEXT Collaboration (90 authors), J. High Energy Phys. 1 (2021) 189
- *"Sensitivity of the NEXT experiment to Xe-124 double electron capture"*, NEXT Collaboration (91 authors), J. High Energy Phys. 2 (2021) 203
- *"Boosting background suppression in the NEXT experiment through Richardson-Lucy deconvolution"*, NEXT Collaboration (103 authors), J. High Energy Phys. 7 (2021) 146
- *"Sensitivity of a tonne-scale NEXT detector for neutrinoless double-beta decay searches"*, NEXT Collaboration (98 authors), J. High Energy Phys. 8 (2021) 164

Theses

- Afonso Paixão Marques: *"Transporte de carga por iões negativos em gases nobres com dopantes eletronegativos"*, 2021-09-20 , (ongoing)



LQXE

Liquid Xenon R&D

Principal Investigator:
Vitaly Chepel (40)

2 ***Researcher(s):***
Francisco Neves (16), Vladimir Solovov (25)

Total FTE:
0.8

Articles in international journals:	**1** Direct contribution **1** Indirect contribution
Books and chapters:	**1**

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 for these experiments 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 would provide 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 that develop 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.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Vitaly Chepel	João veloso (UA)	35.000 €	2020-11-01 / 2022-10-31	CERN/FIS-INS/0026/2019 / Participation in the RD51 Collaboration at CERN
Vitaly Chepel	João veloso (UA)	35.000 €	2022-11-01 / 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.

Assessment of the past year: objectives vs. achievements

In the past year,the group worked in the framework of the project CERN/FIS-INS/0026/2019 funded by the FCT/CERN Fund, where the group is responsible for one of the four tasks. This task foresees experimental studies of a novel concept of double phase liquid xenon detectors attacking, in particular, some known problems related with the liquid surface. In the proposed solution, the liquid surface is defined by a micropattern structure (e.g. THGEM) freely floating in liquid xenon. As the density of the materials used for these structures is lower than that of liquid xenon, it will float on the surface actually defining its shape. Liquid xenon is expected to partly penetrate into the holes where a strong electric field exists thus promoting an efficient electron extraction from the liquid to gas.

According to the plan, the first aim of these studies at the initial stage is to observe the shape of liquid xenon in contact with THGHEM in its holes. For that purpose, a new setup is being developed allowing microscopic visual observation of the liquid xenon/THGEM system at variable angles. The necessary materials for construction of the setup have been mostly acquired, including a robotic system to allow fine positioning of the optical elements. Parts of the system have been designed and some of them already manufactured in the LIP Mecanical Workshop. The system assembly should start in the forthcoming months. Some delay is observed, explained by the general pandemic situation.

Lines of work and objectives for next year

To work on the framework of CERN/FIS-INS/0026/2019 project till the end of October 2022. As foressen in the project program, study THGEM behaviour on the surface of liquid xenon. The following issues should be addressed:

1. Optical observation of the liquid xenon profile in contact with THGEM and other materials.

2. Measurement of charge extraction through the THGEM holes.

Start preparing experiments within CERN/FIS-INS/0013/2021, officially starting in November 2022, aiming at the measurement of the electron extraction probability from liquid xenon using a novel method developed in the group.

Medium-term (3-5 years) prospects

Finish measurements with a floating THGEM on the liquid xenon surface; study electron emission from liquid xenon using a 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/0026/2019 project till 10/2022 and then of CERN/FIS-INS/0013/2021 till 10/2024.

Submit a new proposal to the FCT/CERN Fund to enable further studies.

SWOT Analysis

Strenghts

Highly qualified and internaionally recognized group members with many years of experience in the field of detector development.

Weaknesses

Heavy involvement of the group members in other activities and projects. Degradation of the experimental basis due to chronical desinvestment.

Opportunities

The weaknesses overcome, there is an opportunity for sound contributions to 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

Limited availability of human power. Lack of investments and investment policy in the laboratory. Low priority at LIP.

LqXe

Publications

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

- *"Operation of a novel large area, high gain, single stage gaseous electron multiplier"*, F.D. Amaro, R. Roque, N.V. Duarte, A. Cortez, and J.A. Mir, Journal of Instrumentation 16 (2021) P01033

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

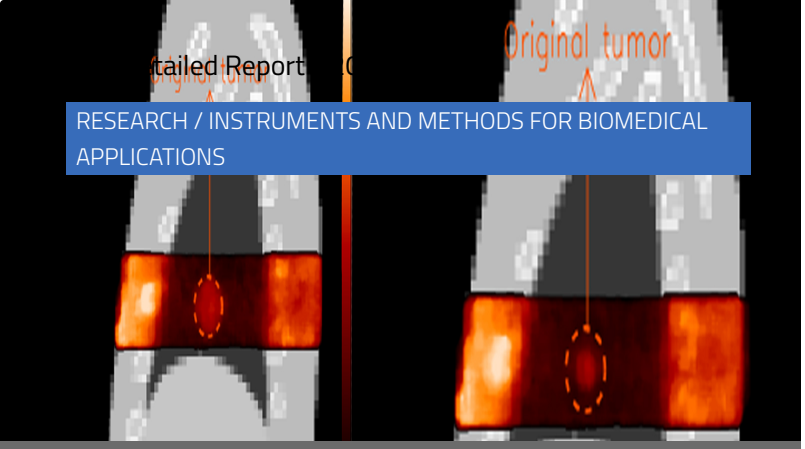
- *"Optical readout studies of the Thick-COBRA gaseous detector"*, F. Garcia, F.M. Brunbauer, M. Lisowskac, H. Müller, E. Oliveri, D. Pfeiffer, L. Ropelewski, J. Samarati, F. Sauli, L. Scharenber, A.L.M. Silva, M. van Stenis, R. Veenhof and J.F.C.A. Veloso, JINST 16 (2021) T01001

1 Book(s)/Chapter(s)

- *"Two-Phase Emission Detectors"*, Dmitry Akimov, Alexander Bolozdynya, Alexey Buzulutskov, Vitaly Chepel,

[Instruments and methods for biomedical applications]

ORimag
Dosimetry



RESEARCH / INSTRUMENTS AND METHODS FOR BIOMEDICAL APPLICATIONS

ORIMAG

Orthogonal Ray Imaging for Radiotherapy Improvement

Principal Investigator:
Paulo Crespo (50)

6 ***Researcher(s):***
Andrey Morozov (40), Hugo Simões (100), Jorge Sampaio (30) (*), Márcia Quaresma (32), Pamela Teubig (25), Patrícia Gonçalves (35) (*)

1 ***PhD Student(s):***
José Miguel Venâncio (50)

3 ***Master Student(s):***
José Pedro Teodoro (50), João Costa Silva (50), Margarida Simões (50)

Total FTE:
5.6

(*) Members of the Dosimetry group collaborating in project CERN/FIS-TEC/0019/2019

Articles in international journals:	**1** Direct contribution
International conferences:	**1** Oral presentation **1** Poster
Nat.& Internat. meetings:	**2** Oral presentations
Collaboration meetings:	**11** Oral presentations
Advanced Training Events:	**2** Oral presentations
Seminars:	**3** Outreach seminars

Executive summary

The work of the OR Imaging group is divided into three main branches: (1) OrthoCT: 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); (2) O-PGI: orthogonal prompt-gamma imaging, for monitoring proton therapy treatments, a collaboration between LIP and the University of Coimbra; and (3) 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.

For Ortho-CT, in 2021 simulations in a phase of near conclusion seem to indicate that results obtained with a monolithic scintillator of GSO (gadolinium oxyorthosilicate) yield comparable images as those obtained with GSO finger-like crystals interleaved within the multislat planes. If variables such as contrast-to-noise ratio or signal-to-noise ratio, yet to be implemented, reveal equal or similar values between the two scintillator configurations, then implementing a monolithic scheme will be the chosen solution, since it represents a rather decreased complexity with respect to the finger-like scintillators approach. This decreased complexity comprehends both the mounting of the scintillator(s), as well as implementing the front-end electronics and data acquisition system.

Regarding O-PGI, during 2021 the group continued two previous GEANT4 studies. Cambraia Lopes et al. (Physica Medica 2018) 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 2021 Morozov et al. (Physica Medica 2021) presented a study where scintillation crystals were used as particle detectors. A proton beam of 130 MeV (typical energies used in head irradiations) was used to irradiate a homogeneous phantom. The latter study included the propagation of the optical photons from the scintillator onto the silicon-based optical detectors. A precision of 2 mm full width at half maximum was demonstrated if the time-of-flight technique is used to reject neutron-induced secondary gamma rays. In the ongoing, GEANT4-based continuation study, we are analyzing the feasibility of performing O-PGI monitoring in the head-and-neck and in the pelvic region. For that, an anthropomorphic digital phantom is being utilized and, for the first time, the whole chain of events is being followed until the detection of the optical photons by silicon-based semiconductor detectors. One PhD and two master students are engaged in these studies. Finally on O-PGI, we plan constructing an O-PGI detector with four slices (five slats interleaved by four rows of YAP scintillators) and study its imaging capability in a clinical proton clyclotron in Delft, The Netherlands (HollandPTC) within the next two years.

In what concerns our simulation engagement with the TPPT consortium, during this year, the work was performed along three main lines. (1) Development of a GEANT4-based framework for comprehensive simulation of the dual-head TOF-PET system; (2) Development, implementation and validation of a custom simulation procedure for generation of the positron emitting species; and (3) Development and implementation of a procedure for building a voxelized anthropomorphic phantom based on the computed tomogram (CT) of a patient. One master student is engaged in part of these activities. The overall goal of these developments 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).

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Paulo Crespo	Patrícia Gonçalves	90.000 €	2020-01-01 / 2021-12-31	CERN/FIS-TEC/0019/2019 / Raditherapy with protons: real time imagiology with gammas and microdosimetry
Paulo Crespo		222.004 €	2020-01-01 / 2022-12-31	LISBOA-01-0247-FEDER-045904 / TPPT - Time of flight PET for Proton Therapy (consortium led by PETsys)
Paulo Crespo	Patrícia Gonçalves	90.000 €	2022-01-01 / 2023-12-31	CERN/FIS-TEC/0017/2021 / 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-rays (OrthoCT), or gamma rays (O-PGI) emitted orthogonally to the treatment beam. Recently 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).

The study of techniques useful in proton therapy is particularly relevant in the context of the installation in Portugal of a centre for proton therapy, with treatment and research facilities. 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:

- Proton therapy: real-time prompt gamma imaging and microdosimetry (PrototerapiaPT+), led by the PI of this group and to be developed in collaboration with the LIP Dosimetry group (CERN fund, between January 2020 and December 2021).
- 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. between January 2020 and December 2022.

As an example of recent progress in e.g. O-PGI studies, a multi-leaf collimator has been fully optimized using extensive GEANT4 simulations and our own reconstruction routines. Even in (simulated) situations where edematous tissue may account for a Bragg peak shift as small as 2 mm, the final results yielded an O-PGI system capable to discriminate clearly such shift. The simulations were obtained with a homogeneous phantom of acrylic. Work is ongoing to determine whether the same precision may be obtained when irradiating the head of an anthropomorphic phantom.

Assessment of the past year: objectives vs. achievements

Last year three lines of work were foreseen.

(1) O-PGI: repeat full simulation with a clinical proton beam with an energy of 200 MeV (prostate and pelvic irradiation with bone tumor in very close vicinity to the spinal cord).

(2) O-PGI: execute and analyze the in-beam experimental results collected at the clinical proton therapy facility in Delft, The Netherlands.

(3) O-PGI and in-beam TOF-PET: adapt one or more DICOM-based (Digital Imaging and Communications in Medicine) computed tomograms and treatment plans (proton therapy) into GEANT4, scoring the prompt gammas that leave the patient so that both O-PGI and PET simulations can be conducted based on this output.

With respect to (1), a full simulation was indeed put forward, and the results were accepted for presentation at the 2022 International Conference on Monte Carlo Techniques for Medical Applications (H. Simões et al., Distal edge determination for a multi-slat prompt-gamma camera: Irradiation with a 200-MeV proton beam). In this simulation work a very large increase in the yield of neutrons at such irradiation energies has been verified, which can be effectively rejected with a proper TOF-window of 1.5 ns FWHM positioned on the peak of arrival of the primary prompt gamma rays. Indeed the non-TOF-rejected prompt-gamma profile reveals no spatial structure to be correlated with the beam range.

In what concerns (2), the experiment to be performed at the TU-Delft site (HollandPTC), this was postponed to a date yet to be determined due to COVID-19 restrictions.

Finally, for (3), regarding the adaption of the DICOM patient tomogram to GEANT4, this has been accomplished for the head of a pediatric patient lent by the MDACC. Adapting a treatment plan onto GEANT4 is still ongoing, with results expected by May 2022.

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 2022:

- OrthoCT: Publish results obtained at the Radiotherapy Department of Coimbra University Hospital Center (first imaging of cavity in homogeneous phantom, with neither X-ray source nor object rotation).
- O-PGI: full simulation of head irradiation (digital anthropomorphic phantom, O-PGI system includes scintillators and visible light detectors)
- O-PGI: optimization of a multi-slat prompt-gamma imaging system for pelvic irradiation.
- In-beam TOF-PET system: full simulation with custom, accelerated simulation code (ongoing).

Three MSc theses and one PhD thesis are ongoing within these lines of work:

- José Pedro Teodoro (MSc. in Biomedical Engineering, Faculdade de Ciências e Tecnologia da Universidade de Coimbra.): Proton therapy monitoring with orthogonal gamma imaging: The case of head irradiation.
- João Costa Silva (MSc. In Physics Engineering, Faculdade de Ciências e Tecnologia da Universidade de Coimbra.): Proton beam distal edge determination with a multi-slat prompt-gamma camera for pelvic irradiation.
- Margarida Nunes Simões (MSc. in Medical Physics): Monte Carlo simulation of beta+ radioactivity generation and its imaging with an in-beam PET system for range monitoring in proton therapy.
- José Patuleia Venâncio (PhD in Technological Physics Engineering, Instituto Superior Técnico da Universidade de Lisboa.): Bragg peak monitoring through prompt-gamma: detection and instrumentation.

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, fiber optics coupled to PMTs, or light-guides connected to either one of the aforementioned light detectors.

In this 3-5 years framework we plan having simulated case-studies with enough detail that 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, total-body 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 dictations obtained from our comprehensive Monte Carlo work.

In addition to concluding the simulations and/or data analysis for both OrthoCT and O-PGI, 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 the end of 2022) the imaging of homogeneous, heterogeneous and anthropomorphic phantoms is envisaged. The plan is to apply for a second Portugal-Austin call so that the in-beam TOF-PET system is applied to real patient treatments.

SWOT Analysis

Strengths

The rotation-free, low-dose imaging capability of OrthoCT and O-PGI are two of their strengths. The imaging capability of both techniques have recently 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 detectors 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 in research by the group, OrthoCT, O-PGI and in-beam TOF-PET 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

Publications

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

- *"Distal edge determination precision for a multi-slat prompt-gamma camera: A comprehensive simulation and optimization of the detection system"*, A. Morozov, H. Simoes, P. Crespo, Phys. Medica 84 (2021) 85-100

Presentations

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

- H. Simões, J. Sampaio, J. Teodoro, V. Lopes, A. Morozov, J. Silva, M.N. Simões, P. Gonçalves, P. Crespo: *"Adapting a computed tomogram to Geant4 for monitoring proton therapy via prompt-gamma rays and time-of-flight PET"*, 2021-09-08, PANIC - Particles an Nuclei International Conference: PANIC - Particles and Nuclei International Conference, Lisbon

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

- TPPT consortium: *"Real-time in-beam positron emission tomography for proton-range verification in proton radiation therapy"*, 2021-10-20, 2021 IEEE NSS/MIC,

2 Oral presentations in national or international meetings

- P. Crespo, P. Assis, A. Morozov, M. Pinto, H. Simões, M.N. Simões, J. Teodoro, J. Miguel Venâncio, P. Gonçalves: *"Influência da tecnologia em medicina: O caso da terapia com protões"*, 2021-03-12, , Universidade de Coimbra
- Paulo Crespo: *"Particle physics techniques applied to health"*, 2021-07-08, LIP Internship Program 2021,

2 Oral presentations in advanced training events

- Paulo Crespo: *"Hadrontherapy"*, 2021-05-13, , Coimbra
- P. Crespo, P. Assis, V. Lopes, A. Morozov, J. Sampaio, J. Silva, H. Simões, M.N. Simões, J. Teodoro, J. Miguel Venâncio, P. Gonçalves: *"Orthogonal Ray Imaging"*, 2021-06-14, LIP's Research Line Strategy Discussion: Health and Biomedical Applications, Coimbra

3 Outreach seminars

- H. Simões: *"Orthogonal ray imaging group: ongoing results"*, 2021-03-04, XVI Encontro Nacional de Estudantes de Engenharia Biomédica, Universidade de Coimbra
- H. Simões: *"OPGI: orthogonal prompt gamma imaging for monitoring proton therapy treatments"*, 2021-05-26, Dia da Investigação do Departamento de Física, Universidade de Coimbra
- H. Simões, A. Morozov, J. Sampaio, M.N. Simões, P. Gonçalves, P. Crespo: *"Development of an in-beam time-of-flight positron emission tomograph for monitoring proton therapy"*, 2021-05-26, Dia da Investigação do Departamento de Física, Universidade de Coimbra

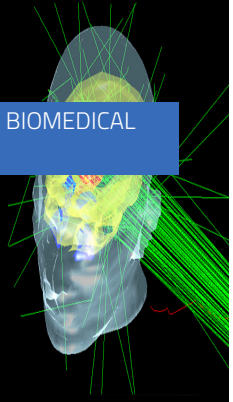
Theses

1 PhD

- José Miguel Venâncio: *"Bragg Peak monitoring through prompt-gamma: detection and instrumentation"*, 2020-09-01 , (ongoing)

3 Master

- José Pedro Teodoro: *"Proton therapy monitoring with orthogonal gamma imaging: The case of head irradiation"*, 2020-09-14 , (ongoing)
- 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 , (ongoing)
- João Costa Silva: *"Proton beam distal edge determination with a multi-slat prompt-gamma camera for pelvic irradiation"*, 2021-01-01 , (ongoing)



DOSIMETRY

Dosimetry

Principal Investigator:
Jorge Sampaio (50)

5 ***Researcher(s):***
Daniel Galaviz (20), João Gentil (10), Luis Peralta (40), Pamela Teubig (20), Patrícia Gonçalves (10)

9 ***PhD Student(s):***
Carina Coelho (75), Dalila Mateus (50), Duarte Guerreiro (100), Joana Antunes (100), Joana Leitão (100), José Miguel Venâncio (50), Maria Giorgi (25), Mariana Brás (30), Miguel Molina (50)

10 ***Master Student(s):***
Ana Campos (20), Cláudia Espinha (84), Cristiana Rodrigues (50), Daniel Salgueiro (100), Filipa Baltazar (84), Lia Pereira (18), Matilde Santos (100), Nísia Fernandes (50), Rita Pestana (17), Tomás Almeida (8)

2 ***Undergraduated Student(s) and Trainee(s):***
Bianca Alves, Madalena Gamboa

Total FTE:
12.6

Articles in international journals:	**1** Direct contribution
International conferences:	**4** Oral presentations **3** Posters **1** Proceeding
National conferences:	**1** Oral presentation
Completed theses:	**4** MScs

Executive summary

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 in 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 research studies in forefront radiotherapy (RT) modalities. To this end, the group has been consolidating its activities in two main areas (but with diverse applications):

- High resolution dosimetry detectors for applications in RT and radiobiology experiments.
- Simulations to advance new modalities in RT.

The first area includes the development of a new detector system capable of measuring energy depositions at the sub-millimeter scale using scintillating plastic optical fibres (SPOFs). The surface of the detector's sensitive area will act as a support for the growth of cell cultures or biological tissues that are to be irradiated. One of the innovative ideas we intend to explore is the possibility of functionalizing cell monolayers on the PMMA coating of the fibers. This project is being developed with the collaboration of cell biology researchers from the Biosystems and Integrative Sciences Institute (BioISI) from the Faculty of Sciences of the University of Lisbon (FCUL).

In the second area we are using Monte Carlo (MC) simulation tools to study the physical and physicochemical effects of radiation and from these infer biological effects. To this end the group has been acquiring skills in the TOPAS code and its extension TOPAS-nBio that allows simulating point-to-point energy deposition processes as well as reactive oxygen species (ROS) production yields. Our group’s students are using and developing applications based on these tools applied to different research subjects, including nanoparticle (NP) radiosensitizing RT (NP-RT), minibeam RT (MBRT), ultrahigh dose rate RT (FLASH-RT), and 177Lu-DOTATATE peptide receptor radionuclide therapy (PRRT). This research is being carried out within the scope of master's and doctoral theses in collaboration with national research centers such as the Center for Nuclear Sciences and Technologies of Instituto Superior Técnico (C2TN-IST), Instituto de Ciências Nucleares Aplicadas à Sáude (ICNAS) from the University of Coimbra, and the Champalimaud Foundation (CF), as well as with foreign research centers such as the German Cancer Research Center (DKFZ) and Institut Curie-Orsay Research Center (IC-CNRS).

The group continues to show the capability to attract students and intends to continue to do so in a sustainable way in order to consolidate the ongoing research areas and collaborations.

Dosimetry

Overview

Currently the Dosimetry group has six researchers corresponding to 1.5 FTE. These researchers are responsible for several research activities, including the supervision of PhD and MSc students. Six students in the group have PhD grants from ProtoTera and three from PT-CERN grant programs.

Researchers and students are divided into the following research activities:

SPOF array for high-resolution dosimetry

This project is supported by several LIP infrastructures: LOMaC, e-CRLab and Mechanical Workshop. It also has the collaboration of F. Herrera from the BioISI research center at FCUL as an expert in the cell biology. Most of the project is being done in the scope of the PhD thesis of D. Guerreiro, supervised by L. Peralta and J. Sampaio. D. Guerreiro is supported by a PT-CERN PhD grant. The new student D. Salgueiro is now starting his MSc thesis on the design of a detector and phantom for proton therapy (PT) based on the SPOF array concept. His thesis is supervised by J. Sampaio and J. Gentil.

Modeling radiobiological effects of nanoparticles

The PhD thesis of J. Antunes focuses on modelling the AuNP-RT radiation effects on glioblastomas multiform (GBM). This work is being developed in the framework of the TPPT project, a collaboration with the ORimaging group, (CENTRO-01-0247-FEDER-045904), under the supervision of J. Sampaio and co-supervised by F. Mendes and A. R. Paulo, both from the radiochemistry group at C2TN. J. Antunes is supported by a ProtoTera PhD grant. T. Almeida is a new student starting his MSc on the design of a phantom for radiobiology experiments applied to NP-RT.

Charged particle MBRT and FLASH-RT

These activities are being carried out in the framework of theses. M. Molina is researching on Monte Carlo simulations of water radiolysis for FLASH proton-MBRT. C. Espinha and J. Leitão are now starting their PhD on computational models for proton and ion MBRT and multi-beam FLASH therapy, respectively. These students are being supervised by P. Gonçalves and João Seco from DKFZ, Germany. M. Giorgi is working on dosimetry studies of MBRT with heavy ions under the supervison of J. Sampaio and Y. Prezado from IC-CNRS, France.

Other activities

Here we include theses projects on other topics that are also part of the research areas of the group. Some of them are just starting and may become standalone activities in future reports. These include the MSDc thesis of C. Rodrigues on the dosimetry assessment of the ^{177}Lu-DOTATATE PRRT and the PhD thesis of D. Mateus on the uncertainties of the output factors for MV small photon fields, both supervised by L. Peralta and in collaboration with the CF.

C. Coelho and L. Pereira are now starting a new topic of research on the effects of proton therapy on protein self-organization and amyloid structures, which could impact neurodegerative disorders. These works are being developed under the supervison of. D. Galaviz and P. Teubig together with F. Herrera from the BioISI, FCUL. C. Coelho is also supported by a ProtoTera PhD grant.

All simulation-related activities make intensive use of LIP FARM resources.

Assessment of the past year: objectives vs. achievements

SPOF array for high-resolution dosimetry

The prototype consists of an array of SPOFs aligned in a frame and connected to a multi-anode photomultiplier (MAPMT) system and a customized Data Acquisition (DAQ) board for signal processing. The design of the detector was finalized and the parts are going to production at LIP's Mechanical workshop.

A special board was constructed to mount the fibers on a frame and to ensure their alignment and different techniques were tested to evaluate it. We have identified that confocal microscopy (CM) available at FCUL allows these tests with the desired resolution and precision. First attempts were also made to connect the 64-fiber array to the MAPMT. The FLUKA MC simulation code was used to study several properties of the detection system, namely the secondary radiation field produced by the ICNAS proton beam and the need of additional shielding on the MAPMT, the optical response of the fiber array to different types of radiation (protons and photons), including crosstalk and fiber misalignment effects.

Modeling radiobiological effects of nanoparticles

The Dosimetry group participates in the TPPT project tasks related to the study of AuNP in the radiosensitization of GBM cells. This activity consists on the development of simulation tools that allow the analysis and interpretation of radiobiology studies foreseen for this task. Last report stated that one of the actions was to develop simulations considering realistic geometries of the cell structures. In the framework of her PhD thesis, J. Antunes obtained CM images of U87 and U-373 cell lines using the equipment at the FCUL Microscopy Facility. She also developed a program to convert the stack of 2D images into a binary file to be imported by the TOPAS code. This program has been successfully tested with an example of a real CM cell image taken from the ImageJ software. However, most images obtained in CM do not have the quality of this example. It is therefore still necessary to optimize the image segmentation process that allows separating the various components of the cells (nucleus and cytoplasm).

Irradiation tests were also performed with the Co-60 source at C2TN/IST as planned in the last report. These experiments consisted of irradiating U-87 and U-373 cell lines followed by clonogenic assays to determine survival curves as a function of dose and concentrations of AuNPs. Based on the simple single spherical cell model, simulations were performed with the TOPAS code. The local effect model (LEM) was applied, considering the source activity, to determine survival fractions for the cells internalized with AuNPs. The results of these simulations are in general agreement with the results obtained in the biological assays. In addition to the LEM model, J. Antunes also started to implement the microdosimetric kinetic model (MKM). For this, she is developing scorers for new quantities in TOPAS following the procedure of Kim et al. 2021.

N. Fernandes finished her MSc thesis on the radiosensitization effect between cells internalized with AuNPs. For this she built monolayer models with different cell densities and sizes in analogy to the morphological properties of pancreatic cancer cell cultures. The simulations were performed for various beam qualities (Co-60 and LINAC). The results show clearly that there are radiation effects between neighboring cells at higher energies (MeV). Moreover, due to the angular distribution of the scattered electrons, it was predicted that the intracellular effects could be more pronounced in 3D spheroid cultures than in 2D monolayers. However, their quantification in terms of dose enhancement factors is hard to compute due to the required simulation times to achieve reasonable statistics.

Charged particle MBRT and FLASH-RT

Last year we started a project related to MBRT with heavy ions. This project is being developed in the framework of M. Giorgi's PhD thesis in collaboration with Y. Prezado from IC-CNRS. The first goals are to establish quality assurance parameters in the context of ion MBRT and perform intercomparison of instruments available in the market. In the first months, the student adapted the existing proton MBRT simulation macro from TOPAS to the carbon MBRT setup to be used in the irradiation experiments planned at GSI. An important limitation of TOPAS is that it has built-in only the proton LET scorer, but we also started developing a new scorer for heavy ions.

M.Molina's work was centered in the study of water radiolysis processes with Monte-Carlo tools such as TOPAS-nBio, Geant4 and gMicroMC, a GPU-based Monte-Carlo simulation code. The use of the latter code initiated a collaboration with the University of Arlington in Texas. J. Leitão and M.Brás are in the initial year of their theses, and they are presently in Heidelberg getting acquainted with the methods and instruments required for the development of their theses.

Other activities

PRRT with ^{177}Lu-DOTATATE is remarkably effective in the treatment of neuroendocrine tumors (NETs) over-expressing somatostatin receptors. The aim of this study was to compare the dosimetry calculated by two computational methods (Voxel S-values or MC) on a retrospective analysis of ^{177}Lu-DOTATATE PRRT clinical cases treated in the CF. This study revealed equivalent 3D absorbed dose maps for both methods, in the abdominal region. This work resulted in a recent publication.

The measurement of field output factors (OF) for MV photon small fields are subjected to large uncertainties, due to the challenging of the small field dosimetry, which involves the lack of electronic equilibrium, source occlusion and volume effect of the used detector. The purpose of this work is to present results of field output factors (OF) using an IBA CC03 (Razor NanoChamber) in parallel and perpendicular orientation in respect to the beam axis and compared these results with the PTW 60019 (MicroDiamond). Our results demonstrate the need of applying field output correction factor k for IBA CC003 for field sizes equal or less than an equivalent square field size of 1 cm, to compensate volume averaging and perturbations effects.

The work on the simulation of I-125 Auger emission spectrum using new atomic parameters was also recently published. This work started a few years ago and shows that our new calculations reproduce much better the Auger spectrum in the region of the K-LL and M peaks. This results in a dose point kernel (DPK) value 8% higher below the 10 nm range than the values currently obtained using standard databases. However, these differences are largely engulfed by the limitations of atomic relaxation models implemented in the current MC simulation programs.

Lines of work and objectives for next year

SPOF array for high-resolution dosimetry

The next steps in this project are to build the prototype and carry out the first tests of the detector response with X-ray, electron and proton beams. We also want to study the feasibility of using this system in quality control in proton RT. For this we will develop in task 4 of the CERN/FIS-TEC/0017/2021 project the concept of the fiber-phantom built with a modular structure consisting of a central module where the detector is embedded, to which additional volumes can be added to increase the size and change shape of the phantom. We will also adapt the detector design to accommodate a system with two perpendicular fiber planes. These activities will be carried out in the scope of D. Guerreiro's PhD thesis and D. Salgueiro's MSc thesis. A proposal for an exploratory project was submitted to an internal FCUL call, including groups from LIP and BioISI.

Modeling radiobiological effects of nanoparticles

In the scope of J. Antunes' thesis, it is intended to finalize the optimization of the algorithm for conversion of CM images to TOPAS geometry. It is also intended to finish the implementation of the analysis of the results of simulations with the MKM model. Next, we will realistically simulate the irradiation conditions envisaged in the

TPPT project and model survival curves and ROS production yields. The results will be compared with the experimental data obtained by the C2TN group for the GBM cell lines. During the next year, the MSc student T. Almeida will design of a phantom for radiobiology studies able to simulate in-depth tumors and in particular applied to RT-NP.

Charged particle MBRT and FLASH-RT

Next year we will start the experimental campaign at GSI regarding pre-clinical studies of MBRT with carbon ions. The student M. Giorgi will be in this campaign under the supervision of Y. Prezado. Furthermore we intend to validate the implementation of the ion LET scorer in TOPAS and to start treatment planning simulations from CT images of anonymised patients in the context of MBRT with heavy ions. Since unacceptable computational times are expected, we intend to investigate the implementation of simulations using GPUs.

The comparison performed by M. Molina between the results of the different tools and the study of the effects of irradiating cells with Mini-beams, in particular with the Monte-Carlo tool gMicroMC, will be the object of a publication that is in the initial preparation phase. J. Leitão will study the FLASH effect in healthy tissue protection using the state-of-the art simulation tools - GEANT4, TOPAS, gMicroMC and TRAX-CHEM. - for describing water radiolysis due to the interaction of proton beams with tissues.
M. Brás work in "adaptive dose reconstruction with online in-vivo range verification in particle therapy", will consist of developing multiple approaches to infer dose distributions from range-information and evaluate them for performance and accuracy.

Other activities

As far as instrumentation is concerned, we would like to start a line of research in fluorescent nuclear track detectors (FNTDs). FNTDs are made of sapphire single crystals doped with carbon and magnesium. The FNTDs when exposed to high-LET radiation produce fluorescence centers along the particle tracks. One of their advantages is that reading does not require a previous chemical treatment. CM associated with image processing software can be used directly on exposed FNTDs to obtain distributions of deposited energy at the nanoscale. We would like to explore this technology and for that we have started a collaboration with C2TN's solid state group which has expertise in crystal growth. To this end we have now been joined by a PhD student within the ProtoTera programme and an exploratory project on this topic will be submitted to FCT in 2022.

In the framework of the study of the impact of proton therapy on protein amyloid structures, first studies of cell irradiation using gamma sources are planned to develop a cell irradiation protocol and verify the threshold levels for stress inducement prior to the execution of irradiation studies with proteins. In collaboration with BioISI, we will combine fluorescence microscopy techniques to evaluate the effect of the radiation. Further studies using X-rays and proton beams are foreseen once the protocol is established.

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 RT 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 hope to have our SPOF array dosimeter prototype tested and validated in a real environment in order to achieve TRL 5/6.

We also plan to improve the group's competencies in the component of simulations at the micro and nanoscale using tools such as Geant4 (-DNA) and TOPAS (-nBiO). The group should also deepen its knowledge in the mathematical models of the biological effects of radiation and extend these skills. These competencies could make the group a relevant partner in national and European consortia for research projects in these areas. To this end, we will strengthen collaborations with other research centers, namely, DKFZ, IC-CNRS, and the UT-MDACC.

SWOT Analysis

Strengths

The dosimetry group has the ability to aggregate several LIP infrastructures into common projects. It has also the potential to attract Biophysics and Physics Engineering students since a few members are teaching at the University. It is consolidating collaborations with several medical and biology research institutions in Portugal (BioISI/FCUL, C2TN/IST, and ICNAS/UC). It is also establishing collaborations with international research centers (DKFZ, IC-CNRS, UT-MDACC).

Weaknesses

The number of FTE researchers is small in relation to the numbers of students. The contractual situation of the group's researchers is in many cases precarious (including the group coordinator). There is no consolidated budget to guarantee medium-term research projects, but it is expected that next year there will be partial funding of some activities through projects coordinated by other groups.

Opportunities

The installation of the PT unit in Portugal will give relevance to the projects proposed in this plan. Specific funds for advanced training in this area are expected to continue with the ProtoTera PhD program. The possibility of developing and consolidating long-standing international collaborations is also foreseen (DKFZ, IC-CNRS, UT-MDACC).

Threats

The contractual volatility of several researchers makes the development of this strategic plan over the next five years uncertain. The lack of long-term funding constrains the development of large-scale and multi-disciplinary projects, hindering the ability to maintain broader collaborations with other research centers. It also limits the material support to the ongoing and future doctoral projects. The sustainability of supervising students also depends on the number of FTE researchers available in the group. As the group grows it will be necessary to avoid too much dispersion of topics.

Dosimetry

Publications

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

- *"Simulation of 125 I Auger emission spectrum with new atomic parameters from MCDHF calculations"*, J.M. Sampaio, J. Ekman, B.P.E. Tee, R. du Rietz, B.Q. Lee, M.S. Pires, P. Jönsson, T. Kibédi , M. Vos , A.E. Stuchbery, and J.P. Marques, J. Quant. Spectr. Rad. Tranf. 227, 107964 (2022)

1 International Conference Proceeding(s)

- *"Comparison of Voxel S-values and Monte Carlo Simulation in [177Lu]Lu-DOTA-TATE Quantification for Patient-Specific Dosimetry"*, Rodrigues, C., Ferreira, P., Oliveira, F. P. M., Silva, Â., Peralta, L., Costa, D. C., Eur J Nucl Med Mol Imaging, 48 (2021) S75

Presentations

4 Oral presentations in international conferences

- D. Guerreiro, M. Santos, J. Sampaio, J. G. Saraiva, L. Peralta: *"Scintillating Array For Real Time High-Resolution Ion Therapy Resolution Ion Therapy Dosimetry: Initial Design And Simulations"*, 2021-09-08, PANIC - Particles an Nuclei International Conference,
- C. Rodrigues, P. Ferreira, F. P. M. Oliveira, Â. Silva, L. Peralta, D. C. Costa: *"Comparison of Voxel S-values and Monte Carlo Simulation in [177Lu]Lu-DOTA-TATE Quantification for Patient-Specific Dosimetry"*, 2021-10-20, 34th Annual Congress of the European Association of Nuclear Medicine, Online
- Rodrigues, C., Ferreira, P., Oliveira, F. P. M., Silva, Â., Peralta, L., Costa, D. C.: *"Comparison of Voxel S-values and Monte Carlo Simulation in 177Lu-DOTA-TATE Quantification for Patient-Specific Dosimetry"*, 2021-10-20, European Association of Nuclear Medicine October 20-23, 2021, Online
- L. Peralta: *"Microdosimetria em tempo real com feixe de protões"*, 2021-12-02, I SIFAM - Simpósio De Física Aplicada à Medicina, Universidade Federal de Uberlândia, Brasil

3 Poster presentations in international conferences

- J. Antunes, F. Mendes, A. Paulo and J. M. Sampaio: *"Modeling the radiobiological effects of gold nanoparticles in proton therapy of glioblastomas"*, 2021-09-07, PANIC - Particles an Nuclei International Conference: PANIC 2021, Particles and Nuclei International Conference, Lisbon
- M. Santos, D. R. Guerreiro, J. G. Saraiva, G. Evans, J. M. Sampaio, L. Peralta, P. Assis, M. Ferreira, J. Nogueira: *"Characterization and functional test of a micro dosimeter of scintillating optical fibers"*, 2021-09-10, PANIC 2021, Particles and Nuclei International Conference, Lisbon
- J. Antunes, F. Mendes, A. Paulo and J. M. Sampaio: *"Modeling the radiobiological effects of gold nanoparticles in proton therapy of glioblastomas"*, 2021-10-20, Connecting the dots: Interdisciplinarity as a way to build up resilience. UT Austin Portugal 2021 Annual Conference, Porto University and online

1 Presentation(s) in national conference(s)

- Joana Antunes, Jorge Sampaio, Luís Peralta: *" Simulation of the Effectiveness of Radiosensitization of Gold Nanoparticles in Proton Therapy."*, 2021-09-02, Física 2020, Lisboa

Theses

9 PhD

- Joana Leitão: *"Developing Multi-Beam FLASH with Proton Beams"*, 2021-10-04 / 2025-10-03, (ongoing)
- José Miguel Venâncio: *"Bragg Peak monitoring through prompt-gamma: detection and instrumentation"*, 2020-09-01 , (ongoing)
- Carina Coelho: *"The effects of proton therapy on protein self-organization: potential benefits for neurodegenerative disorders"*, 2021-10-01 , (ongoing)
- Dalila Mateus: *"Estudos dosimétricos para SBRT/SRT de pequenas lesões do Cérebro"*, 2019-03-07 , (ongoing)
- Duarte Guerreiro: *"Scintillating array for real-time high-resolution ion therapy dosimetry"*, 2020-09-01 , (ongoing)
- Miguel Molina: *"Evaluating the Effectiveness of Mini-Beam Radiation in Cancer Therapy"*, 2021-03-01 , (ongoing)
- Joana Antunes: *"Modeling the radiobiological effects of gold nanoparticles in proton therapy of glioblastomas"*, 2021-02-01 , (ongoing)
- Maria Giorgi: *"Development of a dosimetry protocol for proton minibeam radiotherapy"*, 2021-10-01 , (ongoing)
- Mariana Brás: *"Adaptive dose reconstruction with online in-vivo range verification in particle therapy"*, 2021-09-13 , (ongoing)

10 Master

- Cristiana Rodrigues: *"Comparison of Two 177Lu-DOTATATE Quantification Methods for Patient Personalised Dosimetry in Therapy of Neuroendocrine Tumours"*, 2020-10-01 / 2021-11-10, (finished)
- Filipa Baltazar: *"A Monte Carlo based study of the FLASH effect in radiotherapy with protons"*, 2021-01-01 / 2021-11-26, (finished)
- Cláudia Espinha: *"A computational model for radiotherapy studies with proton mini-beams "*, 2021-01-01 / 2021-12-16, (finished)
- Nísia Fernandes: *"Estudo da radiossensibilização de células tumorais do pâncreas com nanopartículas"*, 2020-11-05 / 2022-01-31, (finished)
- Tomás Almeida: *"Design of a phantom for radiobiology studies"*, 2021-12-01 / 2022-12-31, (ongoing)
- Lia Pereira: *"Modelling protein amyloid structures and observing the effects of radiation using the GEANT4-DNA toolkit"*, 2021-10-04 , (ongoing)
- Rita Pestana: *"Development of a standard methodology for online dose calculation in air "*, 2021-10-01 , (ongoing)
- Ana Campos: *"Estudo da dispersão de partículas alfa em filmes finos"*, 2018-07-01 , (ongoing)
- Matilde Santos: *"Caracterização e teste funcional de um micro dosímetro de fibras ópticas cintilantes"*, 2020-09-14 , (ongoing)
- Daniel Salgueiro: *"Design of a fiber-phantom detector for quality assurance in PT"*, 2021-09-13 , (ongoing)

[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)

4 ***Researcher(s):***
Bernardo Tomé (10), Luisa Arruda (75), Marco Alves Pinto (90), Pedro Assis (10)

1 ***PhD Student(s):***
Pedro Ildefonso (8)

2 ***Master Student(s):***
Carlota Cardoso (28), Igor Miguel Gago (13)

4 ***Undergraduated Student(s) and Trainee(s):***
Alexandre Branco, Anselmo Falorca, Bruno Lourenço, Leonor Candeias

Total FTE:
2.8

Articles in international journals:	**1** Direct contribution **1** Indirect contribution
Notes:	**1** LIP Students note
International conferences:	**3** Oral presentations **2** Posters
Collaboration meetings:	**1** Oral presentation
Advanced Training Events:	**3** Oral presentations
Seminars:	**2** Outreach seminars

Executive summary

In the past 18 years, an area of research and development focused on the study of the different space radiation environments and its effects was implemented and consolidated at LIP. 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:

1. **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.
2. **Radiation Effects Analysis tools**: develop tools to enable precise and user-friendly radiation shielding and effects calculation, including for single event effects (SEE).
3. **Radiation measurement**: Radiation measurement technologies.
4. **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 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.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Patrícia Gonçalves		300.000 €	2014-02-18 / 2022-03-31	ESA: 1-7560/13/NL/HB / RADEM proto-flight model

SpaceRad

Overview

The key topics covered by the SpaceRad Group activities are the following:

1. Study of the radiation environment, in orbit, in interplanetary space and in the 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.
2. 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.
3. 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.
4. 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.
5. 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

The present group activities are centred in the data analysis of 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. Additionally there is a focus in the analysis of the Multiparticle Spectrometer data and of the Component Test Bed results, which integrated the AlphaSAT radiation Environment and Effects Facility, operating in Geostationary Orbit. The group also 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 manned missions to Mars and astrobiology studies.

Assessment of the past year: objectives vs. achievements

The beam tests and calibration of the RADEM Flight Model scheduled to March 2021 were finished in November 2021. The group continued following the work and participating in the Juice Science Working Team for future analysis of cruise data and cross analysis of RADEM data with other instruments on board of JUICE, as planned.

The MFS and CTTB Data Analysis contracts finished. However, there remain five years of scientific data to be analysed. Radiation effects on the CTTB components during the five years of data collection continued to be studied and results are being prepared for publication:

- Correlations of CTTB data with solar activity were presented at RADECS2020 and received the award of the Best data analysis Worskhop paper attributed during RADECS2021 and a paper was published. Data from the three RADFETs, and the SEU and SEL monitors has been used to benchmark the standard radiation environment models for Geostationary orbit, as defined by the European Cooperation for Space Standardization methods to calculate radiation levels in Space missions. Using data from the SEU and SEL monitors, we also showed that CMOS SRAMs are a suitable candidate to measure Solar modulation outside the Earth proton belts.
- A paper on the pioneer study of the effects of radiation in GaN electronics aboard the CTTB is being finalised and submitted for publication. 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 accepted for publication.

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 analyses, was accepted for publication the journal Science Advances

Theses

- Carlota Cardoso started her master thesis on the flight data analysis of the BERM radiation monitor in the characterisation of its flight performance through the analysis of Earth Flyby data from October 2021.
- Igor Gago is starting his master thesis on life prospection on Mars studying the subsurface radiation environment.
- Pedro Ildefonso joined the group to start his PhD theses in December. The topic of study is under evaluation.

Internships

The SpaceRAD group participated in the LIP Summer Internship program.

- Alexandre Branco and Leonor Candeias, were selected to work on “Radiation at Mars with SRAM based monitors”. The results of the internship were published on an internal note.
- Anselmo Falorca and Bruno Lourenço, worked on "Hunting Forbush Decreases in the inner Solar System" using BERM data.
- Mário Amaro, an Aerospatial Engineering student at IST, worked on characterising the radiation environment at different orbits: LEO, MEO and GEO.

Prepared Proposals

Several proposals were prepared for 2021 calls but were not successful:

- To the FCT call for projects in all scientific domains (PTDC): PlanetRAD - Planetary radiation environment predictions and radiation environment modelling for human space flight and astrobiology studies. The project aimed to develop an integrated framework for the characterization of the radiation environment to be used in support of Martian and Lunar exploration and in Astrobiology studies in the subsurface of Mars. The proposal was eligible for funding but not selected (overall rating: 7.3/9).
- PROTECT "Lunar Cube" Science platform for radiation and astrobiology experiments: A proposal to the ESA Open Space Innovation Platform (OSIP) call For ideas, "Exploring the Moon with a large European landeR", led by Peter Weiss, Head of the Space Department in the French company COMEX, in collaboration with the Centre for Interdisciplinary Research in Space from the Norwegian University of Science and Technology. This proposal was not selected.
- A PhD thesis proposal was announced at PT Space call for PhD grants in January 2021.

Lines of work and objectives for next year

The critical issues for next years are the participation of the group in instrument development and science teams for planetary missions (to Mars, Jupiter and to the Moon) both by extending the duration of projects in which LIP is involved and by getting engaged in new ones. In addition, the exploitation and development of installations for radiation tests in Portugal are envisaged and the fostering of an interdisciplinary network to further develop applications and projects in the field of space radiation environment and effects and related areas is aimed. To contribute to ESA’s strategy in guaranteeing independence of the European space sector in critical technologies and to promote innovation and technical excellence in industry are also important guidelines for these efforts.

Ongoing activities

In this context for the next year the Group will be involved in the following activities concerning Radiation Monitors in Space:

- The RADEM contract finishes in the first quarter of 2022. The group will continue to follow the work and to participate in the Juice Science Working Team for future analysis of cruise data and cross analysis of RADEM data with other instruments on board of JUICE. RADEM launched is now foreseen to August 2023.
- The BERM calibration and in-flight data analysis is ongoing, including cross calibration with the SIXS instrument also onboard of BepiColombo.
- The MFS and CTTB Data Analysis - 5 years of scientific data are available to be analysed. A new unfolding method for the MFS measured fluxes still needs to be developed and the MFS data analysis will be readdressed.

The activities concerning the exploration of the GEANT4 based Mars Radiation Environment Model 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 manned missions to Mars.

The strategy used in the development of the dMEREM, the detailed Martian Radiation Environment Model, is the basis for the foreseen development of a Lunar Radiation Environment model, whose preliminary studies and data assessment have been made in the context of the preparation of several proposals.

Proposals and projects in preparation

The BARD project: LIP will be the prime contractor with SE2S, a Swiss PME as sub-contractor, of a three year contract with ESA with the objective of Expert support to BERM & RADEM units on board BepiColombo and JUICE spacecraft. The contract should start in the first quarter of 2022.The group prepared the BARD proposal - Expert support to BERM and RADEM units on board BepiColombo and JUICE spacecraft.

The groups also foresees a participation on the development of a new radiation monitor for the Lagrange mission, EFACEC S.A., PSI and IDEAS, our partners in RADEM. Lagrange is an ESA mission with the objective of enhancing present space weather monitoring capabilities. It will be the first dedicated space weather mission in L5 and the first ever deep space mission providing measurement data in Near Real-Time (NRT). Its foreseen launch date is 2025.

Medium-term (3-5 years) prospects

In the next 3 to 5 years, the SpaceRad group aims to:

- Keep involved in the next phases of the RADEM detector deployment and also in the scientific team of the JUICE mission, in the area of energetic particle radiation environment and effects.
- Explore the potential of RADEM data collected during the cruise phase. As a part of the Cosmic Vision programme, JUICE will spend over three years exploring the Jovian system and its icy moons in particular: Ganymede, Callisto and Europa.

- Within the BepiColombo science team, explore the potential of BERM data and correlate this set of data with the other radiation monitor data in other heliospheric points. LIP joined the effort to check validate the first data. LIP is co-responsible with PSI for in-flight data validation, cross-calibration of BERM with the SIXS instrument, and for developing high-level products.
- Work in the joint analysis of the intraplanetary collected by the two ESA radiation monitors: BERM and RADEM in the BARD project.

  Work in the conception, design and planning of a dedicated radiation monitor for the Lagrange mission together with PSI and EFACEC SA, scheduled to be launched in 2025.
  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 manned missions.
  Strengthen the collaboration with PT-Space, and reinforce international collaborations in the fields of space exploration and space weather.
  Strengthen the interdisciplinary collaboration with groups working on space science and technology at the Lisbon University.

SWOT Analysis

Strengths and Opportunities

- Expertise in GEANT4 for space applications is well developed and LIP is the only Portuguese institution with background in this area in the context of contracts with ESA.
- 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 can be 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.
- Some senior members are deeply involved with academia which facilitates the attraction of new students for the group providing a strong training plataform.
- A senior member is moving to ESA for 2 years merging the gap between the Group and the Agency
- Participation 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.
- Close connection with PT Space, creation of a Space Science and Technologies minor at IST, connection and networking with Portuguese community in Space for science and exploration.

Weaknesses and Threats

- In terms of funding the group heavily depends on contracts with ESA, with a typical duration between 1 year 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.
- No funding obtained in last national FCT call for projects. 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 oportunities for trained students in industry, in Portugal and abroad, while career prospects for Post-docs and young researchers and diffcult.
- Constant networking effort and attention to ESA intended and published invitation to tender calls is required, as well as to EU opportunities or others. 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. The group PI is heavly involved in LIP effort for Proton therapy and in LIP mangement.

SpaceRad

Publications

1 Article(s) 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

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

- *"The in-situ exploration of Jupiter's radiation belts: A White Paper submitted in response to ESA's Voyage 2050 Call."*, E. Rousso et al., Experimental Astronomy (2021)

1 LIP Students Note(s)

- *"Radiation at Mars with SRAM-based monitors"*, Alexandre Miguel Baptista Branco and Leonor de Almeida Candeias, LIP-STUDENTS-21-14

Presentations

3 Oral presentations in international conferences

- C. Poivey, S. Bounasser, M. Pinto, T. Sousa, P. Ribeiro: *"Data Analysis of a Memory Single Event effect Experiment in a Geostationary Orbit"*, 2021-08-31, Single Event Effects (SEE) Symposium, Online
- Patrícia Gonçalves, Luisa Arruda, and Marco Pinto: *"The Radiation Environment on the Surface of Mars: dMEREM predictions based on RAD data"*, 2021-09-22, Europlanet Science Congress 2021, Online
- Sanchez-Cano, B., Vainio, R., Pinto, M.,..., Gonçalves, P. et al.: *"The terrestrial radiation belts as seen by BepiColombo during its flyby to Earth"*, 2021-09-23, Europlanet Science Congress 2021, Online

2 Poster presentations in international conferences

- Elias Roussos, Christina Cohen, Peter Kollmann, Marco Pinto, Patricia Gonçalves, Norbert Krupp, and Konstantinos Dialynas: *"Evidence for local acceleration of heavy >10 MeV/n oxygen and sulphur in Jupiter's innermost radiation belts"*, 2021-09-17, Europlanet Science Congress 2021, Online
- Pinto, M., Gonçalves, P., Cardoso, C., Sanchez-Cano, B., Moissl, R., Vainio, R., Oleynik, P., Huovelin, J., Korpela, S., Lehtolainen, A., Grande, M., and Marques, A.: *"The BepiColombo Radiation Monitor"*, 2021-09-23, Europlanet Science Congress 2021, Online

3 Oral presentations in advanced training events

- Alexandre Branco, Leonor Candeias: *"Radiation at Mars with SRAM-based monitors"*, 2021-09-13, Estágios de Verão do LIP 2021, Online
- Ansalme Falorca, Bruno Alexandre Alves Lourenço: *"Hunting Forbush Decreases in the inner Solar System"*, 2021-09-13, Estágios de Verão do LIP 2021, Online
- Marco Pinto, João Retrê: *"Short course by EPEC: The Communication is Virtual but the Science is Real"*, 2021-09-17, Europlanet Science Congress 2021, Online

2 Outreach seminars

- Luisa Arruda: *"Espaço: Para o infinito e mais além mas em segurança!"*, 2021-10-27, O Espaço vai à Escola- ESERO, Colégio Valsassina Lisboa
- Luisa Arruda: *"Espaço: Para o infinito e mais além mas em segurança!"*, 2021-11-04, O Espaço vai à Escola- ESERO, Externato Champagnat (virtual)

Theses

2 Master

- Carlota Cardoso: *"Flight data analysis of the BERM radiation monitor aboard the BepiColombo mission to Mercury"*, 2021-06-09 / 2022-07-01, (ongoing)
- Igor Miguel Gago: *"Life prospection on Mars - Studing the Martian Subsurface Radiation Environment"*, 2021-11-11 / 2023-10-31, (ongoing)

i-ASTRO

Space Instrumentation for Astrophysics

Principal Investigator:
Rui Curado Silva (31)

4 ***Researcher(s):***
Alessandro de Angelis (5), Filomena Santos (20), Jorge Maia (43), Miguel Moita (10)

1 ***Technician(s):***
Joana Mingacho (43)

1 ***PhD Student(s):***
Alexandre Fonseca Trindade (60)

5 ***Master Student(s):***
André Neves (1), Bárbara Matos (100), Gabriel Salgado (100), Henrique Neves (15), Joana Pereira (1)

1 ***Undergraduated Student(s) and Trainee(s):***
Giorgio Canezin

Total FTE:
4.3

Articles in international journals:	**2** Direct contribution **2** Indirect contribution
International conferences:	**1** Oral presentation **3** Posters **1** Proceeding
Nat.& Internat. meetings:	**1** Oral presentation
Collaboration meetings:	**1** Oral presentation
Seminars:	**4** Seminars **3** Outreach seminars
Completed theses:	**1** MSc

Executive summary

The Space Instrumentation for Astrophysics Group (i-Astro) develops its research activities in the framework of mission proposals to ESA, NASA and EU, in the domain of X- and gamma-ray space astrophysics and Terrestrial Gamma-ray Flashes (TGFs) emission effects on the health of aircraft crews and passengers.

Our group is part of the Activities in 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 three ESA call projects: Gamma-ray Laue Optics and Solid State detectors experiment (GLOSS) onboard the International Space Station (ISS), BEXUS ESA balloon STRATOSpheric POLarimetry with Cadmium Telluride Array (STRATOSPOLCA) experiment and the TGF Monitor experiment onboard the Space Rider. In these projects, our group develops detection space instruments based in CdTe, CZT, CsI, Si solid-state detectors.

The AHEAD2020 EU funded project started in March 2020. Our group is part of WP11 (Work Package 11) "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.

Lead 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 objective of this experiment is to characterize the effects of orbit proton radiation environment on CZT samples onboard the ISS Bartolomeo platform. Since CZT based detectors are developed by our group for the main instrument of high-energy space astrophysical telescopes operating in Low-Earth Orbit (LEO).

Terrestrial Gamma-ray Flash Science and Monitoring for Aviation Safety (TGF Monitor) project funded by FCT address 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. A solution for TGF onboard monitoring is also proposed and a CdTe laboratory monitor prototype will be developed and tested.

The STRATOSPOLCA experiment was launched last September 29th, 2021 on board an ESA Bexus balloon flight to measure the stratospheric background noise for space Compton astrophysics polarimeters. The STRATOSPOLCA instrument is based on a small CdTe 5×5 pixels (each 2×2×10 mm3) prototype that was accommodated in the balloon gondola during a 3 hour flight up to a maximal altitude of 27.7 km.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Rui Curado Silva		30.000 €	2020-03-02 / 2024-12-01	871158-AHEAD 2020 / Integrated Activities for the High Energ...
Rui Curado Silva	Jorge Maia	106.153 €	2021-06-01 / 2024-06-30	4000136945 GLOSS / GLOSS: Gamma-ray Laue Optics and Solid State detectors (PRODEX Experiment Arrangement No. 4000136945)
Rui Curado Silva	Jorge Maia	49.966 €	2022-01-01 / 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 divided in three lines of work associated to three funded projects: 1) AHEAD project; 2) GLOSS project; 3) TGF Monitor project.

1- In the AHEAD line of work our group is contributing to the development of space based spectro-imagers with polarimetric capabilities for high-energy astrophysics.

1.1- In the framework of AHEAD WP11, we are contributing to the development of the COMCUBE prototype. The COMCUBE polarimetric simulation is part of Henrique Neves' master thesis under the supervision of R. Silva and J. Maia.

1.2- In order to optimize the AMEGO mission design and validate the instrument performances, our group has been simulating the polarimetric performance, under the coordination R. Silva and F. Santos. AMEGO Prototype development in the USA was delayed about one year due to COVID-19.

2- The GLOSS project with the goal of evaluating the proton radiation hardness in CdTe/CZT detectors in context of a LEO mission evolved to ESA Euro Material Ageing experiment onboard ISS, under the coordination of J. Maia and R. Silva. Lead by LIP, in collaboration with UBI, INAF, UF, Active Space Technologies and IMEM, the GLOSS experiment is being set onboard the ISS, where a set of CZT crystals for high-energy astrophysics instrumentation will be tested by analyzing their response before and after the flight. The launch to the ISS is scheduled to beginning 2024.

3- The TGF Monitor line of work, under the coordination of J. Maia and R. Silva addresses the TGF emission effects on the health of aircraft crews and passengers may have a real impact on the aircraft safety standards. A solution for TGF onboard monitoring is also proposed and a CdTe laboratory monitor prototype will be developed and tested. TGF measurements onboard the Space Rider are envisaged in the two month maiden flight of this new ESA reusable vehicle.

Assessment of the past year: objectives vs. achievements

Below, the established objectives and comparison with achievements for 2021 are enumerated in the same order as in the previous report, divided by lines of work: 1) AHEAD, 2) GLOSS and 3) Gaseous detectors for astrophysics.

1- In the AHEAD line of work the assessment of objectives vs. achievements can be summarized as follows:

1.1- As expected i-Astro took part in the COMCUBE design development. However the scientific payload prototype integration was delayed due to COVID-19 impact on material delivery and facility access. Consequently, our participation in the development of COMCUBE FPGA system was delayed as well.

1.2 – In the framework of the AMEGO consortium, an extensive simulation study with the MEGAlib toolkit was performed both for AMEGO baseline configuration and for a smaller version called AMEGO-X, that was submitted to the MIDEX NASA call last December 2021. The results, discussion and conclusions of this work were compiled and presented in Gabriel Salgado's master thesis presented last November.

The scheduled AMEGO small size prototype testing at the Duke University beamline was still postponed due to COVID-19 impacts. The i-Astro group will have the role of coordinating the polarization measurements and data analysis. Our objective is to measure the polarization in a high-energy regime (>1 MeV) and prove that AMEGO will be able to perform fine polarimetry in this energy range.

1.3 – As planned, the STRATOSPOLCA experiment was launched with success in an ESA BEXUS program balloon platform from Kiruna, Sweden last September 29th, 2021. The students' team is presently working in the following data analysis objectives:

i- Measure the level of double-events' background, as well as the level of single and multiple events.

ii- Draw a profile of measured single, double and multiple background gamma-ray events as a function of flight altitude.

iii- Compare the results with those obtained when simulating a balloon flight in similar conditions with the polarimetry MEGAlib simulation code, developed by the students' Simulation Team, in order to validate this code and the analysis methods.

2- In collaboration with the Istituto dei Materiali per l'Elettronica e il Magnetismo (IMEM), from Parma Italy, a set of 10 CZT detector similar samples was produced and safety tests were performed to comply with ISS safety standards. The CZT crystals pre-flight tests before the flight in ISS orbit environment were still not performed, since all the samples were sent to ESTEC ESA for tests, and only in 2022 we will receive the samples for testing at LIP.

3- In Gaseous detectors for astrophysics research line experimental results for electron drift parameters for xenon and for CH4 have been obtained and compared. The choice of these gases was based on the abundance of reliable data available in the literature and the difference in drift behavior they exhibit: xenon has high electron diffusion while CH4 has low diffusion. This difference in behavior was quite noticeable in the results and consistent with other results available. The system has proven its capability and we are now able to proceed to measurements in gases for which 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 energy ranges).

Lines of work and objectives for next year

The objectives of the main lines of work, 1) AHEAD; 2) GLOSS; 3) TGF Monitor, for 2022 are:

1- The AHEAD2020 will enter in its third year. Our activities in AHEAD2020 WP11 activities will address COMCUBE demonstrator tasks and will support our participation in ESA BEXUS program and on AMEGO NASA proposal.

1.1- i-Astro will take part in the COMCUBE scientific payload prototype integration task of AHEAD2020 WP11. In particular we will participate 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 AMEGO consortium, i-Astro will contribute to the simulation with MEGAlib toolkit, of a small size prototype experiment postponed for this year at the Duke University beamline, where the i-Astro group will have the role of coordination of the polarization testing, measurements and data analysis. Our objective is to measure the polarization in a high-energy regime (>1 MeV) and prove that AMEGO will be able to perform fine polarimetry in this energy range.

1.3 – The STRATOSPOLCA flight data analysis will completed and the main conclusions concerning double-events, single events and multiple events background level as well as their as a function of flight altitude will be analysed and published. Furthermore comparison between the flight measured results with those obtained when simulating a balloon flight in similar conditions with the MEGAlib in order to validate our simulation code.

2- In the GLOSS research line we will perform the project's tasks for 2022. In collaboration with the Istituto dei Materiali per l'Elettronica e il Magnetismo (IMEM), from Parma Italy, a set of 10 CZT detector similar samples was produced. In order to assess accurately the CZT detector crystals degradation after the flight under ISS orbit environment, scientific performance tests will be performed under CZT crystals, throughout 2022. A new methodology to monitor the displacement damage coefficients caused by proton radiation will the 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 at the beginning of 2024.

3- TGF Monitor line activities for 2022 include both simulation work and the experimental development of a TGF Monitor solution for aircrafts to alert crews and to characterize the magnitude of the TGFs' emissions and for space TGF measurements on board the Space Rider.

3.1- A number of real TGFs will be simulated, that were recorded by different space gamma-ray instruments at various geographic regions. Furthermore, a new simulation code based in GEANT4 will be implemented to calculate the gamma-ray flux and spectrum generated in the relativistic runaway electron avalanche (RREA) in order to address TGF formation open questions, such as its emission mechanisms' components and their respective weight.

3.2- A Space Rider based experiment was selected by ESA and Portugal Space to study the orbital radiation environment effects on CdZnTe (CZT) as well as its scientific potential as TGFs monitor. In 2022 our group should prepare the Interface Request Review (IRD) and the Payload Design Review (PDR), where the payload experiment detector and electronics will be specified as well as the payload enclosure that will interface with Space Rider lockers. Simulations will be performed to estimate the scientific potential of this detector as a TGF monitor as well as a small scientific high-energy all-sky monitor.

Medium-term (3-5 years) prospects

i-Astro 2022-26 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, ASTENA or COMCUBE.

In AHEAD2020, we expect to design and 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. The WP11 will allow to set a new gamma-ray mission proposal for a future ESA or EU call based on cubesat constellation allowing fine high-energy astrophysics at a lower cost, faster launch solutions and high redundancy.

We expect that the 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, and therefore giving 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 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.

The TGF potential impact on aviation safety will be assessed, where the major question "Which are the risks associated with TGF emissions for passengers and crew members of commercial flights?" will be answered with a high confidence level, by considering a significant number of real TGFs. Furthermore, we will estimate the probability of an aircraft to be exposed to TGFs in the regions where these emissions are more likely, i.e. land masses near the tropics.

TGF formation opens questions as the TGF radiation emission components and its respective weight will be also addressed.

The development of a CdTe TGF monitor and its testing on board the Space Rider should enable the evaluation of the observation sensitivity and time resolution. Furthermore, this TGF Monitor holds a high potential to become a spin-off product for aviation safety, namely for end-users such as airline companies, flight-safety institutions, atmospheric science operators and defense institutions, operating in TGF emission regions. Therefore, we expect that this project outcomes will have a real impact in aircraft TGF emission mitigation measures as well as to aircraft safety standards.

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

In the last decade, the 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 as the group responsible.

The LIP / Physics of Coimbra 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

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

- *"Gamma-ray Astrophysics in the MeV Range The ASTROGAM Concept and Beyond"*, A. De Angelis, V. Tatischeff, S. Brandt, A. Bulgarelli, R. Curado da Silva, I. Grenier, L. Hanlon, D. H. Hartmann, M. Hernanz, G. Kanbach, I. Kuvvetli, P. Laurent, M. Mariotti, M. N. Mazziotta, J. Mc Enery, A. Morselli, K. Nakazawa, M. Pearce, J. Rico, X. Wu, S. Zane, A. Zoglauer, Exp. Astron. 51 (2021) 1225-1254
- *"Polarimetry With a Multilayer CdTe Prototype for Soft Gamma-Ray Astrophysics"*, M. Moita, R. M. Curado da Silva, J. M. Maia, E. Caroli, E. Virgilli, N. Auricchio, J. B. Stephen, F. Frontera, S. del Sordo, IEEE Trans. Nucl. Sci. 68 (2021) 2655-2660

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

- *"PHEMTO: the polarimetric high energy modular telescope observatory"*, P. Laurent, F. Acero, V. Beckmann, S. Brandt, F. Cangemi, M. Civitani, M. Clavel, A. Coleiro, R. Curado, P. Ferrando, C. Ferrigno, F. Frontera, F. Gastaldello, D. Götz, C. Gouiffès, V. Grinberg, L. Hanlon, D. Hartmann, P. Maggi, F. Marin, A. Meuris, T. Okajima, G. Pareschi, G. W. Pratt, N. Rea, J. Rodriguez, M. Rossetti, D. Spiga, E. Virgilli & S. Zane, Experimental Astronomy volume 51, pages1143–1173 (2021)
- *"Understanding the origin of the positron annihilation line and the physics of supernova explosions"*, F. Frontera et al. (25 authors), Exp. Astron. 51 (2021) 1175-1202

Presentations

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

- Henrique Neves, Jorge Monteiro, Diogo Marques, Anna Guerman, Rui Curado da Silva, Jorge Maia, Júlio Santos, Jorge Panagopoulos, Yaroslav Mashtakov, Chantal Cappelletti, Angel Arcia Gil, Rovin Perez: *"Preliminary Mission Design of CubeSat for High Energy Astrophysics Polarimetry"*, 2021-10-25, 28th IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS, Dubai, UAE

3 Poster presentations in international conferences

- R.M.Curado da Silva, N. Auricchio, M. Bettelli, E. Caroli, C. Ferrari, L. Ferro, R. Lolli, J. M. Maia, J. Mingach, M. Moita, E. Virgilli and A. Zappettini: *"AGEING OF GE/SI AND CZT SAMPLES FOR SENSORS AND LAUE LENSES OF FUTURE GAMMA-RAY ASTROPHYSICS TELESCOPES"*, 2021-10-20, IEEE NUCLEAR SCIENCE SYMPOSIUM AND MEDICAL IMAGING CONFERENCE, online
- H. Neves, R. M. Curado da Silva, P. Afonso, N. Auricchio, E. Caroli, I. Carmo, M. I. Ferreira, R. Gameiro, J. Gonçalves, A. Lemos, J. M. Maia, D. Marques, B. Matos, A. Mendonça, M. Moita, D. Monteiro, A. Neves, M. Neves, A. Oliveira, I. Oliveira, J. Pereira, P. Póvoa, S. Rodrigues, R. Roque, J. Silva, J. Silveirinha, M. Simões, G. Smith, J. Sousa, D. Torres: *"STRATOSPOLCA: STRATOSpheric POLarimetry with Cadmium telluride Array"*, 2021-10-20, IEEE NUCLEAR SCIENCE SYMPOSIUM AND MEDICAL IMAGING CONFERENCE, online
- M. Moita, L. Ferro, E. Caroli, E. Virgilli, R. Curado da Silva, N. Auricchio, S. del Sordo, J. Maia, J. Stephen, F. Frontera: *"ASTENA's Polarimetric Prospects"*, 2021-12-19, IEEE NUCLEAR SCIENCE SYMPOSIUM AND MEDICAL IMAGING CONFERENCE, online

1 Proceeding(s)

- A. De Angelis, V. Tatischeff, M. Mallamaci*, R. Rando, M. Tavani, U. Oberlack, R. Walter, G. Ambrosi, A. Argan, P. von Ballmoos, D. Bastieri, E. Bernardini, S. Brandt, A. Bulgarelli, A. Bykov, V. Fioretti, I. Grenier, L. Hanlon, D. H. Hartmann, M. Hernanz & 16 others G. Kanbach, I. Kuvvetli, P. Laurent, M. Mariotti, M. N. Mazziotta, J. Mc Enery, S. Mereghetti, A. Morselli, K. Nakazawa, M. Pearce, E. Prandini, J. Rico, R. Curado da Silva, X. Wu, A. Zdziarski, A. Zoglauer: *"All-Sky-ASTROGAM - The MeV Gamma-Ray Companion to Multimessenger Astronomy"*, P o S - Proceedings of Science, 358, [579].

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

- Joana Mingacho, R. M. Curado da Silva, M. Moita, J. M. Maia: *"Are terrestrial gamma-ray flashes a danger or not for passengers and crew members of commercial flights?"*, 2021-06-28, 4th Doctoral Congress in Engineering, Faculty of Engineering of the University of Porto

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

- R. M. Curado da Silva ,J. M. Maia, M. Moita, J. Mingacho: *"Space Rider CdTe Monitor for astrophysics and aviation safety"*, 2021-09-08, XXXI Encontro Nacional de Astronomia e Astrofísica,

4 Seminars

- Rui Curado Silva: *"Como ser astronauta"*, 2021-06-02, , Universidade de Coimbra
- J. M. Maia: *"Effects of Proton Radiation on CdTe Detectors for Gamma-Ray Astrophysics "*, 2021-10-19, , University of Beira Interior, Covilhã
- Joana Mingacho, R. M. Curado da Silva, M. Moita, J. M. Maia: *"Are terrestrial gamma-ray flashes a danger or not for passengers and crew members of commercial flights?"*, 2021-10-20, Café com Física, Departamento de Física da Universidade de Coimbra
- H. Neves, R. M. Curado da Silva, P. Afonso, N. Auricchio, E. Caroli, I. Carmo, M. I. Ferreira, R. Gameiro, J. Gonçalves, A. Lemos, J. M. Maia, D. Marques, B. Matos, A. Mendonça, M. Moita, D. Monteiro, A. Neves, M. Neves, A. Oliveira, I. Oliveira, J. Pereira, P. Póvoa, S. Rodrigues, R. Roque, J. Silva, J. Silveirinha, M. Simões, G. Smith, J. Sousa, D. Torres: *"STRATOSPOLCA:STRATOSpheric POLarimetry with Cadmium Telluride Array"*, 2021-11-02, Café com Física, Departamento de Física, Universidade de Coimbra

3 Outreach seminars

- Rui Curado Silva: *"Como Ser Astronauta"*, 2021-11-11, ESERO - O Espaço vai à Escola, Agrupamento de Escolas de Góis;
- Rui Curado Silva: *"Como ser Astronauta"*, 2021-11-24, ESERO - O Espaço vai à Escola, Agrupamento de Escolas do Paião de Góis
- Rui Curado Silva: *"Aquecimento Global"*, 2021-12-14, ESERO - O Espaço vai à Escola, Agrupamento de Escolas da Sé de Lamego

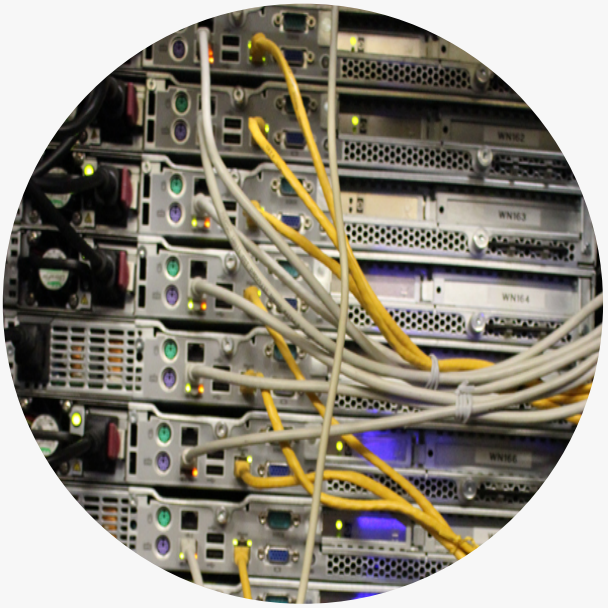
Theses

1 PhD

- Alexandre Fonseca Trindade: *"Study of noble gases mixtures characteristics as a detection medium"*, 2017-01-01 , (ongoing)

3 Master

- Gabriel Salgado: *"Polarimetry for High Energy Astrophysics"*, 2020-09-01 / 2021-11-02, (finished)
- Henrique Neves: *"Constelação de microssatélites para astrofísica multi-mensageira"*, 2020-09-01 , (ongoing)
- Bárbara Matos: *"Radiation detector testing for FORESAIL-2 nanosat"*, 2021-09-01 , (ongoing)



[Scientific Computing]

GRID
AdvCmp
SPAC

GRID

Distributed Computing and Digital Infrastructures

Principal Investigator:
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2 ***Researcher(s):***
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Total FTE:
10.7

Articles in international journals:	**1** Direct contribution
Notes:	**1** Internal note **5** Collaboration notes
International conferences:	**5** Oral presentations
National conferences:	**2** Oral presentations
Nat.& Internat. meetings:	**4** Oral presentations
Collaboration meetings:	**15** Oral presentations
Seminars:	**2** Seminars
Articles in Outreach Journals:	**2** Article in Outreach Journals

Executive summary

The LIP Distributed Computing and Digital Infrastructures Group provides information and communications technology (ICT) 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 simulation, data processing and analysis, including the operation of the Portuguese Tier-2 facility integrated in the CERN Worldwide LHC Computing Grid (WLCG) supporting the ATLAS and CMS experiments. WLCG is a global collaboration of more than 170 computing centres in 42 countries, linking up national and international e-infrastructures to serve the LHC experiments.

The development of the group competences and capabilities is backed by the participation in research, development and innovation (R&D&I) projects at national and international level. The group participates in European projects related to the development and exploitation of digital technologies applied to both compute and data intensive science. The group is currently participating in several H2020 projects: In EOSC-Synergy, developing a platform for quality assurance on-demand for software, services and data; In EOSC-Future, coordinating the software management activities; In EGI-ACE, delivering the middleware management for the EGI infrastructure, supporting cloud applications and working on solutions for wider high performance computing (HPC) integration; In EuroCC, contributing to the national competence center for advanced computing in the framework of EuroHPC. The group also participates 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.

The group is leveraging 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).

Finally, 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.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Jorge Gomes		223.000 €	2017-07-18 / 2022-07-17	INCD 01/SAICT/2016 - nº 022153 / Portuguese National Distributed Computing Infrastructure
Jorge Gomes		338.687 €	2018-01-01 / 2021-03-31	EOSC-hub grant 777536 / Integrating and managing services for the European Open Science Cloud
Jorge Gomes		433.000 €	2019-09-01 / 2022-10-31	EOSC-synergy grant 857647 / European Open Science Cloud – Expanding Capacities by Building Capabilities
Jorge Gomes		249.561 €	2020-03-31 / 2023-03-31	POCI-01-0247-FEDER-045924 LISBOA-01-0247-FEDER-045924 / Big HPC - A Management Framework for Consolidated Big Data and HPC
Jorge Gomes		296.220 €	2020-09-01 / 2022-12-31	EUROCC / Innovating and Widening the HPC use and skills base
Jorge Gomes		196.238 €	2021-02-01 / 2023-08-31	EGI-ACE / Implementing the European Open Science Cloud
Jorge Gomes		160.375 €	2022-01-01 / 2024-12-31	EOSC-Future / EOSC-Future
João Pina	Mário David	29.999 €	2022-03-21 / 2024-03-20	CERN/FIS-COM/0018/2021 / Suporte para o tier-2 de ATLAS e CMS no contexto do WLCG MoU entre Portugal e o CERN
Jorge Gomes		342.812 €	2022-06-01 / 2025-05-31	interTwin / An interdisciplinary Digital Twin Engine for science
Mário David		350.250 €	2022-06-01 / 2025-05-31	AI4EOSC / Artificial Intelligence for the European Open Science Cloud
Jorge Gomes		542.875 €	2022-06-01 / 2025-05-31	DT-GEO / A Digital Twin for GEOphysical extremes
Mário David		222.125 €	2022-06-01 / 2025-05-31	iMagine / Imaging data and services for aquatic science

GRID

Overview

The group activities are organized in four main areas:

- Participation in ICT R&D&I projects to enable the development of competences and capabilities. The group participates in projects addressing several aspects of scientific data processing including: federation of compute and storage resources, massive data management and processing, high performance computing, network related technologies, authentication and authorization, virtualization, data repositories, machine learning, Linux containers, 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 liason with international digital infrastructures and initiatives such as WLCG, EGI, IBERGRID and EOSC. Delivery of compute and data services via the Portuguese National Distributed Computing Infrastructure (INCD). Participation in the national advanced computing network (RNCA).
- Delivery of core 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, graphics 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 process of upgrading the LIP core IT equipment started with funding from the Associate Laboratory programme aiming at a partial renewal of the hardware within the allocated budget. The improvement of the internal IT systems and processes proceeded within the current constraints.

The WLCG Tier-2 supporting the ATLAS and CMS experiments executed more than 486,000 jobs and delivered more than 111,000,000 HEP Spec06 normalized processing hours, corresponding to 110% of the pledged capacity. Overall the reliability was 97%. A small proposal for urgent improvements was submitted to the FCT call for cooperation with CERN but it was cut to less than 29% of the requested budget.

LIP is behind INCD, a multidisciplinary digital infrastructure in the FCT roadmap of research infrastructures of strategic interest. LIP participated in the management bodies of the INCD Association and coordinated all technical activities. LIP is also managing the participation of the INCD Association in several projects. These include the implementation of a national catch-all repository for scientific data in partnership with FCT, implementation of Earth observation services exploiting Copernicus data in the C-Scale project, delivery of cloud computing services to support thematic services in biodiversity and coastal engineering in the EGI-ACE project, and integration of compute and data services in the framework of the EOSC-Synergy project.

In 2021, INCD delivered 33,323,114 CPU hours. Limitations in the datacenter hosting the Bob supercomputer, whose capacity is partially managed by INCD, have decreased the overall capacity by 30%. In Lisbon the migration of the computing cluster was completed and all capacity is now available through the new Slurm batch system. Aiming at improving the reliability of INCD internal services, a Kubernetes container orchestration system is under deployment exploiting the concept of Stateful Application Mobility. This system will complement the existing virtualization platform. Technical specifications for an international public tender to acquire compute and data storage for INCD in 2022 were defined. An expression of interest for the continuation of the INCD in the infrastructures roadmap was prepared.

Collaboration towards a national advanced computing network (RNCA) continued with participation in the RNCA Sherpas group, which is establishing the foundations for this FCT network joining scientific computing centres in the country. The joint LIP/INCD team supported more than 40 computing projects from the 1st FCT call for advanced computing projects. The team also participated in the preparation of the 2nd FCT call for advanced computing projects launched in the Summer. Finally, the formal acession of INCD to the RNCA network as an operational centre was signed with FCT.

In the context of the EuroHPC initiative for a world class supercomputing ecosystem in Europe, LIP participated in the EuroCC project to establish a national advanced computing competence center. LIP coordinated the awareness creation and communication task and participated in the support, consulting, technology transfer and training activities. LIP also participated in the BigHPC project that is developing a framework to support Big Data applications in HPC environments; the contributions were mainly focused on quality assurance, monitoring and containers support.

LIP continued to ensure liaison and coordination with the EGI and IBERGRID infrastructures that federate computing centres across Europe, including INCD. The WLCG Tier-2 is one of the supported communities; other scientific domains supported by LIP with INCD include biodiversity, life sciences, health, coastal and estuarine engineering, structural biology, and oceanography.

Participation in the European Open Science Cloud (EOSC) continued with the participation in the EOSC-Synergy project, aiming to align national infrastructures and policies in Spain, Portugal, UK, Czech Republic, Germany, Slovakia, Poland and The Netherlands. LIP coordinated the work on fostering services adoption where it is pursuing a quality based approach for software, services and data. LIP coordinated the definition of quality criteria and continued to develop the Jenkins Pipeline Library, a core component of the EOSC-Synergy quality-assurance-as-a-service platform. LIP also assisted the partners developing thematic services for EOSC to adhere to quality best practices.
The EGI-ACE project started in 2021. LIP is participating in the tasks for HPC integration, delivery of services for machine learning, management of the cloud and compute middleware for the EGI international federation, implementation of new processes and software repositories for middleware artifacts, and federation of the Iberian nodes of the Global Biodiversity Infrastructure (GBIF). The EOSC-Future project also started in 2021, with LIP providing software and IT service management for the EOSC core.

Finally four project proposals to Horizon Europe were prepared and submitted namely: interTwin, DT-GEO, AI4EOSC and iMagine.

Lines of work and objectives for next year

IT services

Improve the LIP core IT equipment in the framework of the Associate Laboratory programme. The largest share of the funding will be executed in 2022 with the objetive of replacing and improving the LIP own network, storage and virtualization systems that support research and administrative activities. The upgrade will enable better resiliency and higher capacity and new or updated software solutions.

WLCG and Tier-2

A small increase in storage capacity is foreseen through the CERN fund project approved in 2021. A small increase in compute capacity is also expected through INCD. The evolution of WLCG and of the ATLAS and CMS computing models will be followed. The group will continue working with the LIP management to seek solutions for the sustainability and improvement of the LIP computing facilities including the Tier-2. An upgrade of the network bandwidth is foreseen within the FCT-FCCN RCTS 100 project. Evaluation of new solutions and technologies for data handling will take place aiming at higher efficiency.

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 liasion. The INCD computing services are federated in IBERGRID and EGI, and LIP will continue operating them and supporting international research communities using distributed computing. 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 the scope of EOSC participation in EOSC-Synergy and EOSC-Future will continue. EOSC-Synergy will finish in October and the development of the quality assurance platform will be the main focus. In EOSC-Future the service management activities will continue. LIP aims to organize the IBERGRID conference during 2022.

R&D&I projects

Four new projects will start in 2022. The projects AI4EOSC and IMAGINE are focused on the support to artificial inteligence (AI) applications. AI4EOSC continues 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. Several of these projects also relate to the EGI and IBERGRID activities.

The participation in the BigHPC project with TACC, INESC-TEC and WAVECOM will continue now focused on the validation of the BigHPC framework for big data applications in HPC environments. All four project proposals submitted to Horizon Europe calls in 2021 were approved and these projects will start along the year.

EuroHPC and RNCA

The participation in the the national advanced computing competence center (NCC) in the EuroCC project will continue. The main focus will be put on the awareness creation and communication task coordinated by LIP, and in the training and knowleadge transfer activities. The project has been extended until the end of 2022, and a follow-up project is already being discussed to support the network of NCCs across Europe. 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.

INCD

The INCD main project under the FCT infrastructures roadmap finishes in July 2022. INCD applied to the FCT call for expressions of interest in the roadmap, however no funding calls are currently scheduled. This situation opens a temporal and funding gap whose dimension is unknown. The focus during 2022 will be in maintaining the infrastructure operational. A final public tender to improve the INCD hardware is ongoing, and will hopefully enable a small capacity improvement in Lisbon, new offline storage in Coimbra and new

computing capacity to be deployed at UTAD. The energy costs for 2022 are supported by agreements with FCT, which also include a protocol for the implementation of a national catchall scientific data repository. In addition LIP coordinates the INCD participation in the projects EOSC-Synergy, EGI-ACE and C-Scale where INCD is supporting the integration and delivery of services for specific communities. Again together with LIP and in the same scope, INCD will also participate in the new project iMagine.

Medium-term (3-5 years) prospects

Participation in international digital infrastructures and initiatives is expected to continue with participation in EGI, IBERGRID and EOSC. Participation in EOSC task forces and projects will continue namely with the projects EOSC-Future and EGI-ACE finishing in 2023. The national competence center in EuroCC/EuroHPC is expected to continue with a follow-up project. Participation in further projects will be pursued 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 pursed within the scope of INCD and exploiting alternate funding sources when viable. The WLCG technical architecture and the Tier-2 will likely evolve over the coming years seeking higher performance and efficiency.

The group aims to continue participating in INCD and coordinate the technical activities. The funding from the FCT research infrastructures roadmap will finish in 2022. An expression of interest to continue and further develop INCD was submitted to FCT, however actual calls for funding are not expected until 2023. Meanwhile the objective will be to position and prepare to apply to a second phase of the research infrastructures roadmap.

The participation in the national advanced computing network will proceed, now formally with INCD as one of the operational centers supporting the FCT calls for advanced computing projects. Collaboration with FCCN in the area of scientific data repositories will be pursued leveraging the INCD capacity and the group expertise from the participation in EOSC projects.

The four project proposals submitted to Horizon Europe in September 2021 were all approved and the corresponding 36 month projects interTwin, DT-GEO, AI4EOSC and iMagine will start in September 2022.

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 European projects, namelly in the framework of the European Open Science Cloud.
- 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.

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.
- Possible participation in the second phase of the FCT infrastructures roadmap.

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.
- Extremely difficult to contract and retain skilled personnel.

GRID

Publications

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

- *"Forecasting contrasting coastal and estuarine hydrodynamics with OPENCoastS"*, A. Oliveira, A.B. Fortunato, M. Rodrigues, A. Azevedo, J. Rogeiro, S. Bernardo, Laura Lavaud, Xavier Bertin, Alphonse Nahon, Gonçalo de Jesus, Miguel Rocha, P. Lopes, Environmental Modelling & Software, Volume 143, 2021

2 Institute reports

- *"INCD Plano de Atividades e Orçamento 2021"*, Jorge Gomes, João Pina et al,
- *"INCD Relatório de Atividades e Contas 2021"*, Jorge Gomes, João Pina et al,

1 Internal Note(s)

- *"EuroCC T19.7 Plan of Activities 2021 awareness creation and collaboration"*, Jorge Gomes, João Pina, Hugo Gomes, Carlos Manuel, Catarina Ortigão,

16 Collaboration notes with internal referee

- *"BigHPC Deliverable 5.1 - Plan for software integration, validation and pilot activities"*, Samuel Bernardo, Mário David,
- *"EOSC-Synergy 1st Periodic Technical Report"*, Isabel Campos, Jorge Gomes et all,
- *"EOSC-Synergy: M3.4 Badges issuance implemented"*, Pablo Orviz, Jorge Gomes, Germán Mólto,
- *"EOSC-Future D7.1 EOSC Service Planning"*, João Pina et all,
- *"EuroCC T19.7 technical progress Report Nov 2021"*, Jorge Gomes, João Pina, Hugo Gomes, Carlos Manuel, Catarina Ortigão

2 Articles in Outreach Journals

- *"Testes no novo cabo submarino EllaLink"*, Jorge Gomes,
- *" 4th Blog Post - About SW Quality Assurance, Service Integration and Pilot Testbeds"*, Mário David, Samuel Bernardo,

Presentations

5 Oral presentations in international conferences

- João Pina: *"WLCG Computing and Big Data"*, 2021-07-07, 12th Advanced Doctoral Conference On Computing, Electrical And Industrial Systems, Caparica, Portugal
- Jorge Gomes, Sergio Novaes, Rogerio Lope, Jadir Silva, Pedro Lorga, Mario Reale: *"Bella Demo: High Energy Physics"*, 2021-09-02, TICAL Conference 2021, Virtual
- Mário David et all: *"A quality based approach to software and services"*, 2021-10-19, EGI Conference 2021, Virtual
- Jorge Gomes, Diana M. Naranjo, Fernando Aguilar, Germán Moltó, Isabel Bernal, Mário David, Pablo Orviz, Samuel Bernardo, Vyacheslav Tykhonov, Wilko Steinhoff: *"SQAaaS: Fostering Service Integration"*, 2021-10-19, EGI Conference 2021, Virtual
- Pablo Orviz, Samuel Bernardo et all: *"SQAaaS Web Demo: so simple that you can't miss it"*, 2021-10-19, EGI Conference 2021, Virtual

4 Oral presentations in national or international meetings

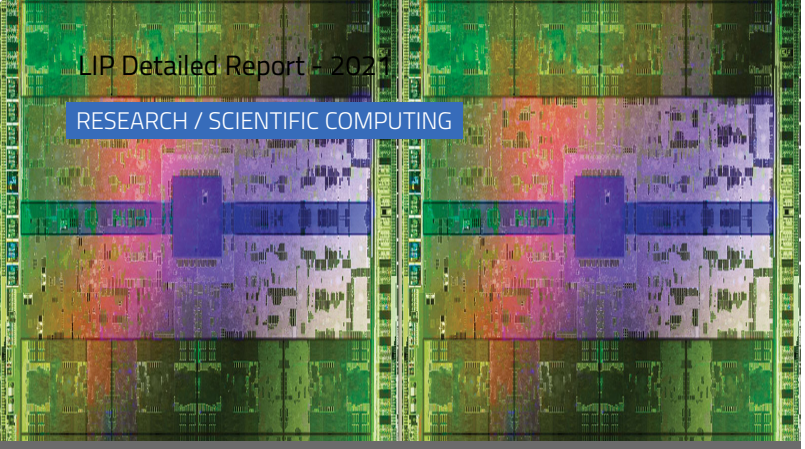
- Mário David, Marcus Hardt et all: *"The Current Onboarding Procedures, Rules of Participation EOSC-Synergy"*, 2021-01-31, Service Onboarding EOSC Task Force, online
- Jorge Gomes et all: *"Software and Services Quality-as-a-Service"*, 2021-04-06, Expands Workshop, Virtual
- Mario David, Roksana Wilk: *"EOSC Synergy proposals"*, 2021-06-05, EOSC Pillar Workshop, Virtual
- Isabel Campos (CSIC), Diana M. Naranjo (UPV), Jorge Gomes (LIP / INCD), Mário David (LIP), Pablo Orviz (CSIC), Slava Tykhonov (DANS): *"EOSC Synergy: SQAaaS"*, 2021-06-14, Dataverse Community Meeting 2021, Virtual

2 Presentations in national conferences

- Jorge Gomes: *"Infraestrutura Nacional de Computação Distribuída"*, 2021-09-29, Encontro RNCA 2021, Virtual
- Hugo Gomes, Catarina Ortigão, Jorge Gomes, Elana Araujo: *"EuroCC Portugal"*, 2021-09-29, Encontro RNCA 2021, Virtual

2 Seminars

- Jorge Gomes, Mário David: *"Running containers in your user space with udocker"*, 2021-06-23, EGI seminars, Virtual
- Mário David: *"Software Development in modern days: DevOps methodology"*, 2021-06-30, ISEL Seminar, Virtual



RESEARCH / SCIENTIFIC COMPUTING

ADVCMP

Advanced Computing

Principal Investigator:
António Pina (75)

1 ***Master Student(s):***
Tiago Duarte (50)

3 ***External collaborator(s):***
António Esteves, José Rufino, Vítor Oliveira

Total FTE:
1.2

Completed theses: **1** MSc

Executive summary

Members of the Advanced Computing group have previous work in Grid, HPC, computing models, high performance communication libraries and distributed data structures. Research also encompass R&D on the combination of traditional multicore CPUs with acceleration devices.

The group, part of the LIP-Minho since the beginning of 2014, has been directing its activity to the fields of Computer Science and Engineering more closely related to the principal areas of interests of LIP research. In particular, it is noteworthy the support for the development and optimization of code applications related to high energy physics and the search for explicit distribution strategies for access to large volumes of data, in order to improve efficiency and execution times.

In particular, it is noteworthy the support for the development and optimization of code applications related to high energy physics and the search for explicit distribution strategies for access to large volumes of data, in order to improve efficiency and execution times. More recently the group embraced new topics related to the areas of big data and machine learning. Another important dimension of activity is the support to advanced training in Scientific Computing.

The group is also responsible for the administration of a local HPC cluster that supports the running of the data analysis applications developed by other groups at LIP and a CPU/GPU system dedicated to machine learning simulation.

The possibility of the group's activities being integrated into the Distributed Computing group from 2022 on is currently being studied, due mainly to the significant reduction in the number of active elements of the group.

AdvCmp

Overview

The Advanced Computing group, part of the LIP-Minho since the beginning of 2014, has been directing its activity to the fields of Computer Science and Engineering more closely related to the principal areas of interests of LIP research.

In particular, it is noteworthy the support for the development and optimization of code applications related to high energy physics and the search for explicit distribution strategies for access to large volumes of data, in order to improve efficiency and execution times. More recently the group embraced new topics related to the areas of big data and machine learning. Another important dimension of activity is the support to advanced training in Scientific Computing.

The group is also responsible for the administration of a local HPC cluster that supports the running of the data analysis applications developed by other groups at LIP and a CPU/GPU system dedicated to machine learning simulation.

The possibility of the group's activities being integrated into the Distributed Computing group from 2022 on is currently being studied, due mainly to the significant reduction in the number of active elements of the group.

Assessment of the past year: objectives vs. achievements

The work developed closely followed the objectives set for the year 2021. In this context, the emphasis was placed on the following activities:

- Continue the process of enriching the pedagogical projects we are responsible for to include R&D in areas directly related to HEP software, in order to foster the interest of young researchers in the work developed at LIP.
- Launch a new computer training activity for young researchers.
- Involvement in the ATLAS collaboration.
- Involvement in the preparation of the project proposal “Anomaly detection as a tool for discovery in high energy physics and beyond”, not funded.
- Concluded of a MSc thesis related to parallel/distributed multithread programming.
- Infrastructures maintenance and administration:
  - local HPC computer cluster infrastructure
  - CPU/GPU Linux platform dedicated to Machine Learning evaluation

Lines of work and objectives for next year

In 2022, the work will continue focused on the research of the themes already identified such as: application performance analysis, dynamic tracing, parallelization strategies for GPU based algorithms, cluster distributed file systems. At the same time we will continue to maintain the local computing infra-structure Cluster infrastructure and the CPU/GPU machine learning system.

We also expected to be able to attract new students for R&D in the group main scientific areas, in particular:
i) performance analyse of HEP data analysis applications.
ii) evaluation of alternatives for developing hybrid shared/distributed memory applications.
iii) development of a platform intended to allow for the efficient processing of data integration

In accordance with our pedagogical and training objectives, we foresee the completion of two ongoing master thesis:

- The first pursues R&D in task-based, fine-grained programming / execution models, with an emphasis on the tools available for monitoring and evaluating the performance of HPX applications.
- The second is directly related to development of applications that combines traditional multicore CPUs with acceleration, taking as a case study the ATLAS Topological Clustering algorithm using GPUs and CUDA.

Medium-term (3-5 years) prospects

The significant reduction in the number of active elements of the group, already identified, makes it difficult to define realistic R&D scenarios in the medium term. In this context, we expect that our strategy of attracting students to the R&D areas related to the group's domain of competence may increase the critical mass of the group, in order to foster the establishment of activity prospects for the coming years. The success in the applications for FCT Call for SR&TD Project Grants and the CERN PhD Grants Program could represent a turning point in the research activities of our group.

Finally, it is important to mention that the current PI of this group, who used to be a professor at the Universidade do Minho, is retired since August 2021, but remains a member of the LIP research team.

In this context, the possibility of the group's activities being integrated into the Distributed Computing group in 2022 is currently being studied.

SWOT Analysis

Strenghts

A group with solid foundation in the parallel and distributed computing scientific domains; International R&D collaboration experience as a result of the active participation in several EU projects; Experience in the promotion of advanced learning and knowledge exchange in scientific computing among young scientists and engineers; Expertise in combining traditional multicore CPUs with acceleration devices.

Weaknesses

We are currently a small group, clearly insufficient to take advantage from the scientific and industrial potential of one of the youngest regions in Europe.

Opportunities

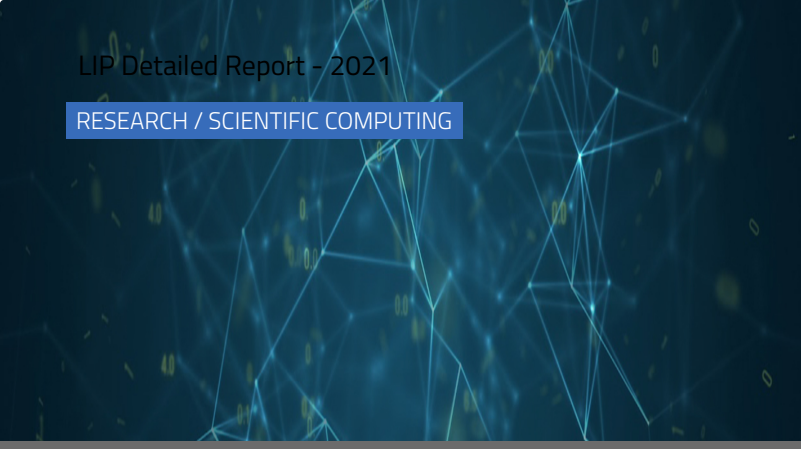
Collaboration with other groups that need to optimize their HEP data analysis code applications; Expertise in combining traditional multicore CPUs with acceleration devices already proved to be and asset in the ATLAS TopoCluster algorithm parallelization; Administration of the local Tier 3 HPC cluster for the exploitation of new system architectures to allow efficiency increase of resource usage to support the increase in the complexity of current applications.

Threats

Local HPC infrastructure has no guarantee of continuity of service by lack of financial support for equipment maintenance/upgrade and system administration; In Portugal, there are no unemployed graduates in Computer Engineering. In this context, it is very difficult to attract to scientific work young people, without the availability of funds to support new scholarships for MSc or PhD.

Theses

- Tiago Duarte: *"Treino de redes neuronais profundas de forma distribuída"*, 2018-10-01 / 2021-03-31, (finished)



SPAC

Social Physics and Complexity

Principal Investigator:
Joana Gonçalves-Sá (80)

4 ***Researcher(s):***
Alexander Davidson (40), Cristina Mendonça (100), Lília Perfeito (100), Simone Lackner (100)

1 ***Technician(s):***
Paulo Almeida (100)

1 ***PhD Student(s):***
Sara Mesquita (100)

1 ***Master Student(s):***
José Reis (100)

1 ***Additional LIP collaborator(s):***
Rita Saraiva

7 ***External collaborator(s):***
Afonso Manuel Marques, David Almeida (*), Eleonora Tulumello (*), Irma Varela-Lasheras (*), Nuno Pereira, Pedro Araújo (*), Sofia Pinto

Total FTE:
7.7

Articles in international journals:	**1** Direct contribution
Preprint:	**1** Preprint
Proposals:	**1** Proposal(s) and related studies
International conferences:	**6** Oral presentations **2** Posters
Advanced Training Events:	**4** Oral presentations
Seminars:	**6** Seminars **10** Outreach seminars
Articles in Outreach Journals:	**2** Article in Outreach Journals

(*) These group members are funded by an FCT-funded project hosted by the PI's previous institution. E. Tulumello and I. Varela-Lasheras are post-doc researchers. D. Almeida and P. Araújo are MSc students.

Executive summary

The 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 complex systems 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 2021, SPAC set the cornerstones of the FARE project, namely designing the large-scale survey and designing the databases. Two manuscripts are in the last stages of preparation and the team is actively collecting “big” data. In parallel, SPAC participated in the pandemic control efforts, in collaboration with different entities. As part of these efforts, a roadmap for COVID-19 surveillance was publicly released.

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Joana Gonçalves-Sá		1.499.844 €	2020-10-01 / 2025-09-30	FARE - Fake News and Real People (ERC) / Grant Agreement 853566

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. Every group member is involved in different projects and contributes his or hers expertise in collaborative and collegial ways. SPAC currently has 12 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

2021 was effectively the first year of SPAC at LIP. SPAC has received significant support from the Institute but many of the challenges have been logistic and of sustaining research and developing infrastructure. The group has yet to physically establish itself at LIP and remains working mostly online.

Four main goals were accomplished:

1. Building team capacity, maintaining team spirit and mental health;
2. Supporting the pandemic control efforts;
3. Establishing the foundations of the FARE project, most notably the computational and data infrastructure to support the necessary future analysis;
4. Assuring the quality and safety of the data pipelines and processes, complying with the GDPR and the EU ethical and privacy standards.

Research Team and Funding

With support from the administrative staff at LIP, ERC project "Fake News and Real People – Using Big Data to Understand Human Behaviour (FARE)" - awarded to SPAC's PI Joana Gonçalves de Sá, successfully started in October 2020 and its execution has been going according to the planned schedule.

SPAC currently has 12 members: 1 PI, 5 Post-doctoral researchers (supported by FARE and an FCT-funded project), 1 PhD student (individual FCT fellowship), 3 MSc students, 1 Data Manager and 1 Project Manager (half-time). After a period of significant growth in size during 2020 and early 2021, SPAC is consolidating its team and should reach its maximum size of 14 members 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, etc.) aimed at facilitating collaboration and interaction between group members. Given the current pandemic context, the remote work, and the fact that most SPAC members are new to the team, particular care was taken to ensure team members became familiar with each other and their very distinct skill sets. 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 analysing 40 years of Portuguese political discourse. This work has led to a large corpus of the parliamentary debates (published in November 2021), one searchable repository, open and of free access to journalists and the scientific community, one in-depth report, sponsored by the Calouste Gulbenkian Foundation, on the public salience of "Intergenerational Justice" as a political concept, and one manuscript submitted during 2021 (currently under review).

Research on the current pandemic has led to two working papers, both on medrxiv. One was submitted for publication in 2021 and is being revised. In parallel, several group members actively collaborate with national health authorities on mitigation and information capacity building and participated in a broad effort to produce a roadmap for pandemic control, made publicly available in March 2021. In parallel, all group members received full training in GDPR and compliance with the EU privacy standards and SPAC should become officially certified during 2022.

Several group members had their work accepted in the main conferences in the field. Together, SPAC members gave 6 oral presentations and 2 poster presentations in international conferences during 2021, and Joana Gonçalves de Sá was an invited speaker at 6 seminars or conferences. SPAC also revised and launched an updated website in October 2021, with a commitment to produce monthly posts and articles aimed at general audiences.

SPAC's PI is strongly involved in science communication and outreach and was distinguished with the "Mulher Activa" award in the Science category. During 2021, Joana Gonçalves de Sá participated in 8 round tables, both in Portuguese and English, wrote 2 newspaper opinion articles and gave 5 interviews to the media, both on disinformation and COVID-19 control.

Overall, SPAC has accomplished several important goals and is in a very good position to begin 2022.

Lines of work and objectives for next year

In 2022, SPAC expects to continue establishing itself as a leading research group in complexity and social physics and increasing its national and international standing.

Having finished the Political Discourse project, as described above, 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 2021, with strong emphasis on research and on supporting the mitigation efforts of the COVID-19 pandemic, and will continue in 2022. 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 nowcasting.
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 2022.
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.

Human Resources

Following the strong growth of 2020 and early 2021, the goal is to cement the current team and limit new hires to one post-doc. In parallel, and as most group members are being supported by 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 pandemic-control efforts. This includes ongoing collaborations with the national health authorities in both database creation and analysis, vaccination roll-out, etc.;
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;
4. Finishing and pilot-testing a large-scale, online-based, behavioral survey;
5. Defining strategies for computationally sound and ethical social media analytics, including establishing collaborations in the areas of distributed computing and encryption;
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 resources.

The group is fully-funded for the next 4 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 2022, we expect that 2 postdocs will apply for independent funding.

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

Team working mostly online and not yet fully consolidated; Limited history of collaboration with researchers at LIP or with LIP's main research partners.

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

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

- *" PTPARL-D: An Annotated Corpus of 40 years of Portuguese Parliamentary Debates."*, Paulo Almeida, Manuel Marques-Pita, Joana Gonçalves-Sá, Corpora

1 Preprint(s)

- *"Learning from pandemics: using extraordinary events can improve disease now-casting models"*, Sara Mesquita, Cláudio Haupt Vieira, Lília Perfeito, Joana Gonçalves-Sá, medRXiv

1 Proposal(s) and related studies

- *"Proposta de mapa de controlo pandémico"*, Various authors,

2 Articles in Outreach Journals

- *"Hospitais vão começar a fazer escolhas impossíveis já esta semana"*, Joana Gonçalves-Sá, Visão
- *"Se os dados são as galinhas, como se guardam as capoeiras?"*, Joana Gonçalves-Sá, Público

Presentations

6 Oral presentations in international conferences

- Lília Perfeito and Joana Gonçalves-Sá: *"A Popularity Model for Information Spreading: Twitter as a Case Study has been accepted as a lightning talk at the conference"*, 2021-07-08, Networks 2021: A Joint Sunbelt and NetSci Conference, online
- Sara Mesquita, Lília Perfeito and Joana Gonçalves-Sá: *"Using online searches and Social Media during pandemics to improve now-casting models."*, 2021-07-10, Networks 2021: A Joint Sunbelt and NetSci Conference, online
- Irma Varela-Lasheras, Sara Mesquita, Lília Perfeito, Pedro Rio, Cláudia Soares and Joana Gonçalves-Sá: *"Flu or Not: A computational approach to respiratory-disease surveillance"*, 2021-07-28, IC2S2 2021 - 7th International Conference on Computational Social Science, online/Zurich, Switzerland
- Lília Perfeito and Joana Gonçalves-Sá: *"An evolutionary model for the spread of information on Twitter"*, 2021-07-30, IC2S2 2021 - 7th International Conference on Computational Social Science, online/Zurich, Switzerland
- Lília Perfeito and Joana Gonçalves-Sá: *"An evolutionary model for the spread of information on Twitter"*, 2021-10-26, CCS 2021 - Conference on Complex Systems, online/Lyon, France
- Simone Lackner, Frederico Francisco and Joana Gonçalves-Sá: *"A Little Knowledge Is A Dangerous Thing: Excess Confidence Explains Negative Attitudes Towards Science"*, 2021-10-26, CCS 2021 - Conference on Complex Systems, online/Lyon, France

2 Poster presentations in international conferences

- Sara Mesquita, Lília Perfeito and Joana Gonçalves-Sá: *"Using online searches and Social Media during pandemics to improve now-casting models."*, 2021-07-29, C2S2 2021 - 7th International Conference on Computational Social Science, online/Zurich, Switzerland
- Simone Lackner, Joana Gonçalves-Sá and Frederico Francisco: *"A little Knowledge is a Dangerous Thing: Excess Confidence Explains Negative Attitudes Towards Science"*, 2021-07-31, IC2S2 2021 - 7th International Conference on Computational Social Science, online/Zurich, Switzerland

4 Oral presentations in advanced training events

- Sara Mesquita: *"Health Information Systems"*, 2021-03-11, Tele-health, Integrated Master Degree in Medicine - NOVA Medical School, online
- Joana Gonçalves-Sá: *"Digital Epidemiology"*, 2021-04-08, Tele-health, Integrated Master Degree in Medicine - NOVA Medical School, online
- Joana Gonçalves: *"Digital Epidemiology"*, 2021-06-15, Summer Institute in Computational Social Science - Lisbon, online/Lisbon, Portugal
- Sara Mesquita: *"The Power of Data - from data to information"*, 2021-11-30, Logistics and Operations Management, Specialization Course in Hospital Administration 2021 - National School of Public Health (ENSP-NOVA), Lisbon, Portugal

6 Seminars

- Joana Gonçalves-Sá: *"The Gordian Knot of Fighting Disinformation"*, 2021-04-15, International Seminar on Hybrid Threats including Disinformation, online
- Joana Gonçalves-Sá: *"The importance of data-analysis for decision making"*, 2021-06-18, 17th European Forum of Official Gazettes, online
- Joana Gonçalves-Sá: *"Tale of two pandemics: a computational approach to the study of disease spreading"*, 2021-09-27, DBE Seminars - Autumn 2021, online/Lisbon, Portugal
- Joana Gonçalves-Sá: *"Graduate Program Science for Development"*, 2021-10-01, Diversidade – um desafio para as ciências da vida e de saúde, online/Porto, Portugal
- Joana Gonçalves-Sá: *"A little knowledge is a dangerous thing: excess confidence, science communication and negative attitudes towards science"*, 2021-10-07, iMED Conference 13.0, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Are The Least Knowledgeable Unaware Of It? A Statistical Revisitation Of The Dunning-Kruger Effect"*, 2021-11-24, CEAUL and CEMAT Seminars, online/Lisbon, Portugal

10 Outreach seminars

- Joana Gonçalves-Sá: *"Science & misinformation: the first pandemic in the digital age (roundtable)"*, 2021-03-22, Science Media Days, European Science-Media Hub, online
- Joana Gonçalves-Sá: *"A little knowledge is a dangerous thing"*, 2021-03-24, Encontros de Comunicação em Ciência(s) - Desafios de comunicar ciência: incerteza e desinformação em tempos de pandemia, online
- Joana Gonçalves-Sá: *"Ciência nos PALOP através do PGCD"*, 2021-05-06, o C da Ciência (podcast),
- Joana Gonçalves-Sá: *"Unpacking bias: perspectives from neuroscience and social psychology (roundtable)"*, 2021-06-17, Ar Events, Champalimaud Research, online
- Joana Gonçalves-Sá: *"Vamos Falar de Ética*

- Joana Gonçalves-Sá: *"Vamos Falar de Ética e Dados (roundtable)"*, 2021-06-17, Vamos Falar de Ética e Dados, NOS, online
- Joana Gonçalves-Sá: *"Data for Artificial Intelligence: Are we leveraging the full potential of EHR? (roundtable)"*, 2021-06-18, Healthcare in Post-Pandemic: will value in health be the way after Covid19?, online
- Joana Gonçalves-Sá: *"Para uma discussão aberta em torno do projecto "Curiosci: Restoring Curiosity at the Hearth of Science Communication - Particle Physics as a Case Study""*, 2021-06-24, SciComPt 2021 - Congresso Anual de Comunicação de Ciência, online
- Joana Gonçalves-Sá: *"Fiction and Fake (roundtable)"*, 2021-06-26, Inside Out, Culturgest, Lisbon, Portugal Joana Gonçalves-Sá: *"Digital transition (roundtable)"*, 2021-08-29, Summer CEmp 2021, online/Alcoutim, Portugal
- Joana Gonçalves-Sá: "Digital transition (roundtable)", 2021-08-29, Summer CEmp 2021, online/Alcoutim, Portugal
- Joana Gonçalves-Sá: *"A Verdade e a Mentira: Comunicação em Saúde e Liberdade de Expressão (roundtable)"*, 2021-12-07, Choque frontal, Lisbon, Portugal

Theses

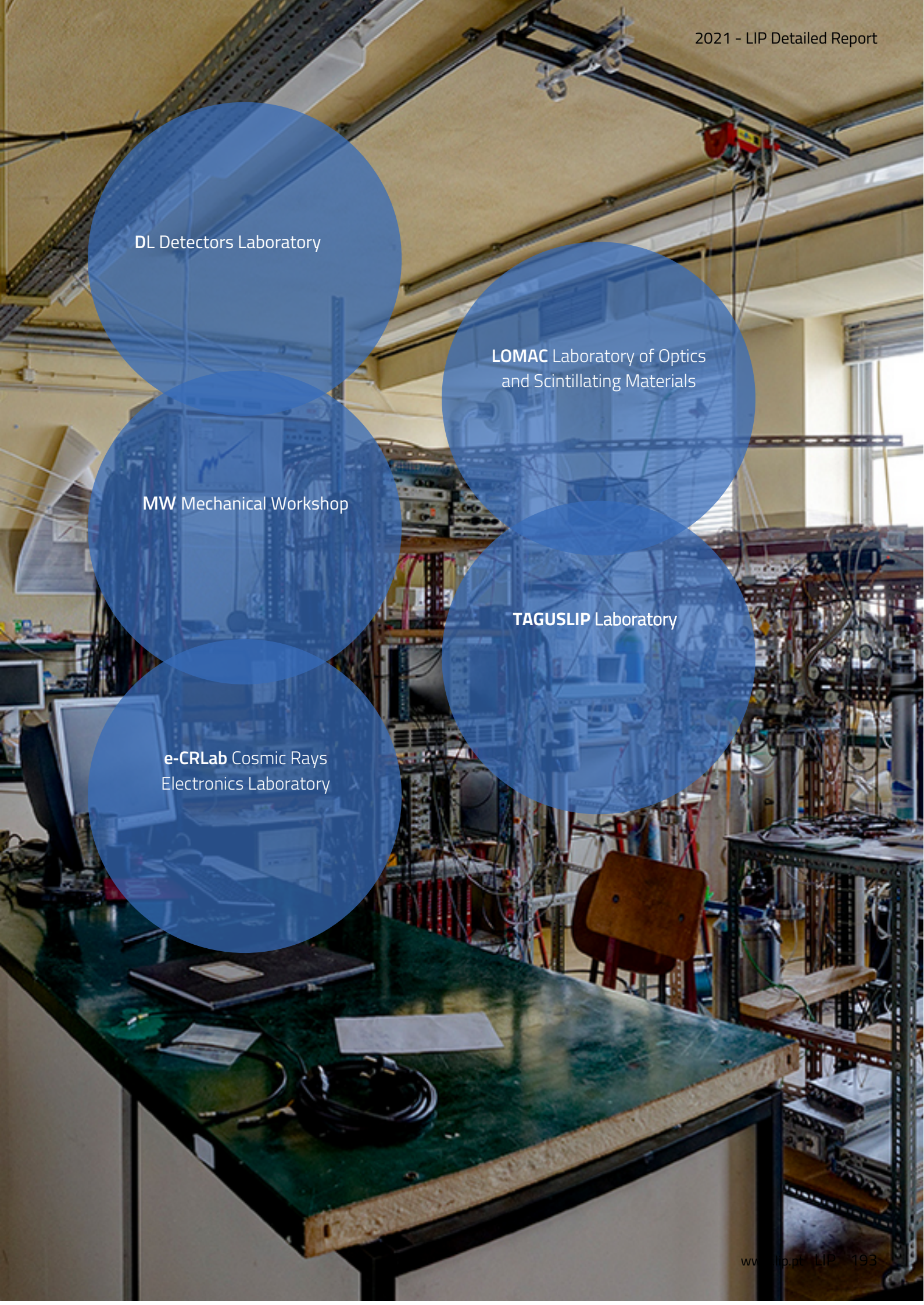
1 PhD

- Sara Mesquita: *"Using online behaviour to track global outbreaks and pandemics"*, 2020-09-01, (ongoing)

2 Master

- David Almeida: *"Follow the (scientific) leader: the impact of crisis on trust in scientific authorities"*, 2020-09-14 / 2022-02-28, (ongoing)
- José Reis: *"Doing the Research: Differential Tracking in Disinformation Websites and its Impact on Search Engine Results and Third-Party Content"*, 2020-09-01 , (ongoing)

RESEARCH Facilities


DL Detectors Laboratory
LOMAC Laboratory of Optics and Scintillating Materials
MW Mechanical Workshop
TAGUSLIP Laboratory
e-CRLab Cosmic Rays Electronics Laboratory

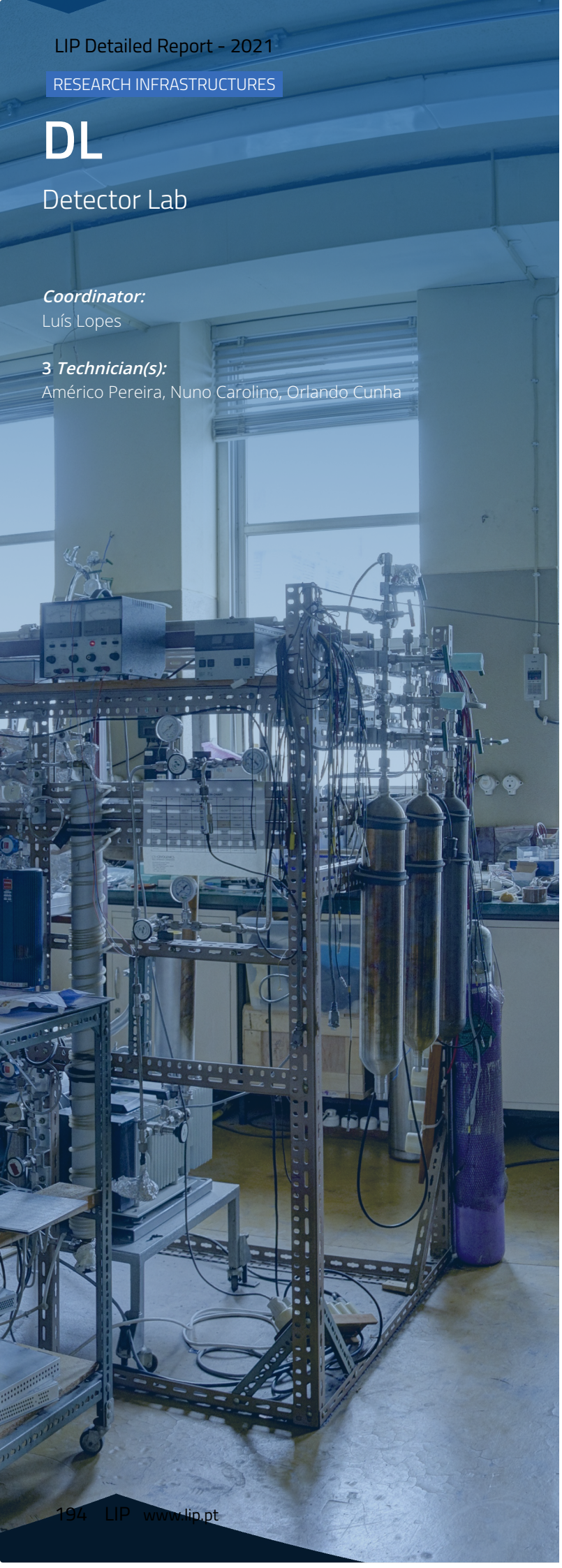
RESEARCH INFRASTRUCTURES

DL

Detector Lab

Coordinator:
Luís Lopes

3 *Technician(s):*
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. While the pandemic impacted the activity plan in several ways, the DL managed to keep all its commitments and to increase the number and magnitude of the services for external entities.

The main activities in 2021 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. R&D and production of new products for outreach is a goal postponed to next year due to the absence of one collaborator since June. Nevertheless we were able to give an adequate response to all the requests from internal and external groups.

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, it is equipped most of the instrumentation and tools needed in a detectors research laboratory. Each group has an independent work area to assemble their setups and develop their activities. The work related to R&D and production of electronics for all groups 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, 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

In spite of the pandemic, LIP's DL was able to fulfill most of the objectives scheduled for 2021. Highlights were, first of all, the production of the HiRezBrainPET scanner in collaboration with the Mechanical Workshop, and also the production and installation in situ of the second half of the HADES-FD detector at GSI.

The main activities in 2021 concerned the development and production of three different types of large area Resistive Plate Chambers (RPCs) used in experiments and projects in which LIP is involved, namely HADES-FD, STRATOS, and HiRezBrainPET. The contribution of the DL to these projects spans from project design to the installation and maintenance of the detectors, following a procedure similar to industry's. It includes the development of the sensitive volume and of the gas control and monitoring system; adapting the detector to the individual requirements of each application; as well as the development of tools and/or instruments to control/monitor the detector performance and the relevant environmental properties. Other parts and systems were developed in collaboration with the project researchers. This work consumed around 60% of our total human resources.

A fundamental role of the DL is the continuous support it provides to all LIP groups performing R&D activities. In 2021 the DL contributed with technical work and added value to the following projects: HiRezBrainPET, DUNE, HADES-TOF and HADES-FD, R3B, STRATOS, Cloud Chambers, Gaseous Detectors, ORimaging, CCMC/ECOTOP, Dark Matter, STRATOSPOLCA, RD51 and SND@LHC. Besides detector work, this included the layout, loading and testing of in-house developed electronic boards. This consumed about another 30% of our human resources.The collaboration with other infrastructures and competence centers has strongly increased.

The work on the sealed RPC was postponed to 2022 due to lack time: besides the above mentioned absence of a collaborator since June, the group leader started accumulating the coordination of the DL with the coordination of the Mechanical Workshop.

The installation of the clean chamber continues to be held by the bureaucracy required by the Technical Department of the University.

Direct contracts for the provision of services and products by the DL to external clients amounted to 5% of our human-power and returned over 5 k€ (around 5% of the annual staff cost).

Lines of work and objectives for next year

In spite of the huge bureaucratic difficulties, to continue pushing for the improvement of the new facilities (F2) is mandatory to achieve the established production targets. We hope to install the ISO 6 Clean Chamber and open the possibility to develop and construct different kinds of detectors and instruments. This objective is transported again from last year.

In 2022, 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. Overall, we expect the production of large area RPCs to be lower this year. Also scheduled is the production of Spark Chambers for outreach purposed. In addition, we plan to produce: HV power supplies; gas monitoring and/or control systems; boards for charge and time measurements. First products based on sealed RPCs will surely become available.

Concerning the support to LIP groups, the DL is expected to contribute in the constructing, assembly and test of the following projects and/or setups: RPCs for neutron detectors

within the RPC_Advance project; Cloud Chambers; Gaseous detectors; HADES; DUNE; CCMC/ECOTOP; Dark Matter, RD51 and many others. There will be, in addition, R&D contributions for several projects, namely HADES-MDC and MuTom RPCs for muon tomography. We also plan to maintain or increase the weight of the work contracts with external groups.

Overall, the goal of the DL is to give an important contribution to LIP, 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 30 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. This was clearly affected by the pandemic and the loss of one collaborator. Nevertheless we already had some contacts and good indications for the delivery of three spark chambers. The shared coordination between DL and MW is of the outmost importance to achive this objective since it allow 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 a support infrastructure, we must follow the needs and options of the research groups.

SWOT Analysis

Strengths

- Our well equipped lab and multidisciplinary 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.

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.
- 20 to 25% of the jobs with more than 5 days of execution time are requested less than a month in advance, or the information needed to execute them is only available within the same short time frame. In this way it is impossible to make an efficient programing.
- There is frequently inefficiency (waste of time) due to bad preparation of the work when our collaborators/clients do not consult the DL experts in advance. We systematically alert our collaborators for the need to do so, and there seems to be an improvement with respect to past years, but we need more commitment.

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

MW

Mechanical Workshop

Coordinator:
Luís Lopes

4 Technician(s):
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 (two technicians and three engineers) allow 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 a support pillar for the future, but as a reason to improve the performance for a continued and sustained growth.

Workshop

Overview

The Mechanical Workshop is well prepared both in terms of equipment and of specialized human resources. There are 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, the production can start to be prepared at an early stage, contributing to an optimized execution of each job.

The new coordination of the MW identified and changed some situations and processes, in view of a better performance of the group.

Assessment of the past year: objectives vs. achievements

All the main projects (HrezBrainPET, protoDune TPC and HADES RPC-FD) scheduled for 2021 were completed respecting the pre-defined delivery times. For all these projects non-scheduled work was also performed.

During the year new projects arised and we were able to cope with all of them. A good example was the production (including project/design checking) of the mechanics for the upstream and downstream modules for the SND@LHC collaboration. A large number of "small" requests for LIP groups were received, which included design, production and test.

We significantly increase the number of external clients, especially among universities and national research centres, which should be our main field of action. This line consumed around 20% of our human resources and returned profits of 10 k€. Some of our 2021 clients were: CNC-Centro de Neurociências e Biologia Celular, TEandM-Tecnologia e Engenharia de Materiais S.A., ITAV-Instituto do Ambiente, Tecnologia e Vida, Universidade de Santiago de Compostela, SerQ-Centro de Inovação e Competências da Floresta, IT-Instituto de Telecomunicações, Unidade de Quimica e Fisica Molecular, HIDRONAV Technologies SL, ICNAS-Produção, MARE-UC, 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 largest project already scheduled for 2022 is the work for the next phase of DUNE.
In addition, a large number of small (one week or less) requests are scheduled, and some more already in the design phase.
The improvement of the work space will also consume some time.
External collaborations are being prepared and hopefully will be a reality this year.

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 intrincate problems. In this line, we will connect the old CNC machines to our CAN 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 technical staff; The possibility to easily extend our services to other research centres and companies; The new capabilities brought in by the new large-area CNC machine.

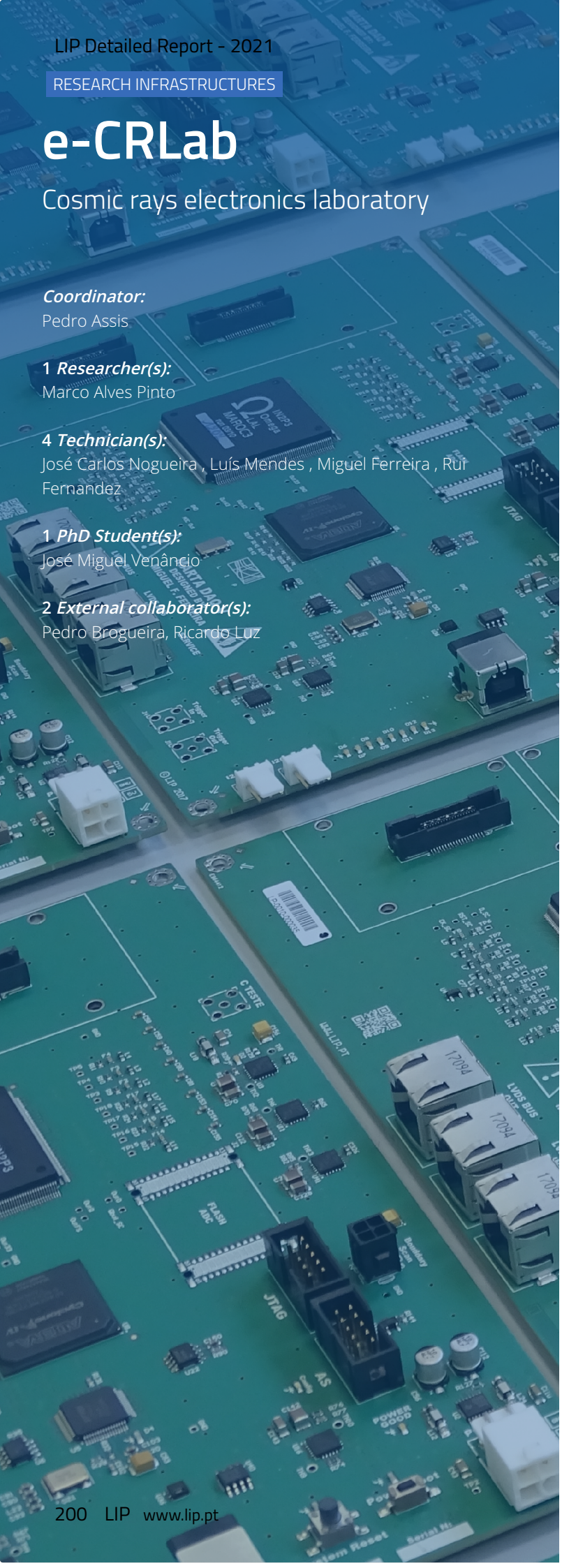
Weakness and Threats

The need for better space organization; The need for better communication between all the parts involved in the projects; The need for more commitment and focus in some tasks; Many old machines and tools no longer used need to be sent out; this task already started; There is the need for better communication within the group, in order to improve performance and reduce mistakes; The new coordinator must improve his knowledge in some important fields, manly 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

1 ***Researcher(s):***
Marco Alves Pinto

4 ***Technician(s):***
José Carlos Nogueira , Luís Mendes , Miguel Ferreira , Rui Fernandez

1 ***PhD Student(s):***
José Miguel Venâncio

2 ***External collaborator(s):***
Pedro Brogueira, Ricardo Luz

Executive summary

The e-CRLab is mainly dedicated to the development of electronics for Cosmic Ray experiments. The focus is put on fast digital electronics implemented in field-programmable gate arrays (FPGAs). The laboratory has the capability to design complex printed circuit boards and to produce simple printed circuit board (PCB) prototypes. The production of complex PCB and its assembly is outsourced. There is also the capability to do rework in PCB boards. A small set of mechanical tools allows for the production of simple detector prototypes, mainly for proofs of concept.

In 2021 the e-CRLab had two main activities: the development of MARTA instrumentation and the development of muon hodoscopes. MARTA is a project within the Portuguese collaboration in the Pierre Auger Observatory to operate RPCs under the Observatory's water Cherenkov tanks. The electronic systems were developed at the e-CRLab, which has the responsibility of their deployment and operation. The MARTA front-end electronics based in the MAROC ASIC was deployed and the slow control and central unit were developed. Hodoscopes were also developed and are not only a test-bench for MARTA but also used to benchmark other detectors used in Auger. Similar hodoscopes are being used in the context of SWGO and MuTom projects for demonstration purposes.

The laboratory has also given support to different groups, including the Space-Rad group with the development and production of hardware, and to the ATLAS group involved in the development of electronics for the LHC upgrade. Great effort was put in the support to the project of the new HV supply system for the Tilecal. Two novel axis of development are being pursued: fast electronics in the ATLAS upgrade context and electronics and instrumentation for medical physics.

The e-CRLab has also been involved in outreach and teaching. The e-CRLab participated in the installation at IST of experimental setups for the Advanced Experimental Physics Laboratory and other educational activities. These setups focus mainly on the detection of cosmic rays and on the study of scintillator detectors.

e-CRLab

Overview

The e-CRLab (electronics for Cosmic Ray Laboratory) is dedicated mainly to the development of electronics for Cosmic Ray experiments. The focus is put on fast digital electronics implemented in FPGAs. The laboratory has the capability to design complex printed circuit boards and to produce simple PCB prototypes. The production of complex PCB and its assembly is outsourced. There is also the capability to rework PCB boards. Recently the laboratory has also focused on the development of embedded systems for data acquisition, slow controls and monitoring. A small set of mechanical tools allows to produce simple detector prototypes, mainly for proofs of concept.

The laboratory facilities are located at LIP-Lisboa and include an office room, an instrumentation room with state-of-the-art equipment, an instrumentation room dedicated to fast electronics for ATLAS, and a separate detector instrumentation room. A small mechanical workshop for detector prototype development and a dark room are available to complement the activities. The laboratory counts on two researchers, one PhD student and four electronics technicians.

Assessment of the past year: objectives vs. achievements

The pandemic has had a great impact on the laboratory's activities. To minimize the transmission risk, in-person activities have been reduced to a minimum. Whenever possible we dedicated more time to design and system development complemented with remote meetings. Nevertheless, even such activities are much more efficient when performed in the laboratory context. Moreover, we are dealing with the lack of EEE components in the global market that seems to be a consequence of the pandemic.

Another impact were the restrictions in traveling to Argentina. The e-CRLab has a very important role in the development and commissioning of the MARTA electronics, which was heavily affected. In this context we developed the solutions necessary to address the issues previosuly found in the field. The system for MARTA is now mature and tested in the lab, waiting for a possibility for deployment in Argentina.

A new tomography setup for the Lousal mine has been built, with 4 planes using the Marta DAQ. The prototype system has been developed by the LIP-Coimbra RPC group, with auxiliary hardware for trigger, synchronization and readout. It is now pending on the availability of the Central Unit.

A novel setup of a hodoscope has been installed at LIP Lisboa, consisting of two MARTA RPC planes separated by ~3 m. It will be used to test the developed systems and to test other detectors.

The developments in the MARTA Front-End were adopted for other projects. A collaboration has started with a Belgian group who purchased one MARTA DAQ system for tests.

The e-CRLab was deeply involved in the development of the HV system for the Tilecal of ATLAS. Namely the infrastructure has given a strong support on the HV supplies board and the prototype system interconnect. The infrastructure was also of utmost importance to identify and propose solutions for the several test setups and interconnects.

The infrastructure has one technician recently hired to work on the ATLAS upgrade. Work started on the HTT system for ATLAS, but the focus is now on the High Granularity Timing Detector (HGTD). Contributions are expected to be twofold: on the DCS and on the testing and development of the ALTIROC ASIC for fast timing. This contribution will be part of the in-kind contribution of Portugal to the experiment.

The reequipment program allowed to acquire a fast oscilloscope to develop the capabilities of the laboratory. The reequipment planning is focused on the development of the capabilities to deal with faster, complex and more integrated electronics.

Lines of work and objectives for next year

The activities of the laboratory are becoming more diversified, which poses some challenges.

We aim at the full commissioning of the MARTA systems and to turn the MARTA DAQ acquisition into a stable system that can be used in several project as an almost off-the shelf system. Part of the main DAQ board is redesigned to have internal intelligenc and further interconnectivity capabilitites.

On the HV power supply for ATLAS we will consolidate the design and provide support for the production and test of the systems. Although the HTT was not approved for the upgrade, we plan to follow the developments led by the Penn U. group, namely the tests of the fast link solutions implemented.

In what concerns the HGTD activities for the ATLAS upgrade, we will contribute to the development of the DCS system and to the testing of the DAQ solution. On the former, we expect to contribute to the interconnection and DCS data stream through the Felix interface. On the latter we will be involved in the tests of the novel ASIC for the readout of the LGAD

sensors, the ALTIROC. The ALTIROC is being designed by OMEGA and shares part of the architectures with the MAROC.

There is also the opportunity to participate in proton therapy projects. A PhD student is currently investigating the design of a DAQ system for prompt-gamma with the group of Paulo Crespo at Coimbra. We also expect to participate in the development of dosimeter systems for activities related with radiotherapy, in collaboration with the LIP Dosimetry group. We will also explore the collaboration with the Valencia group and the Heidelberg group for the development of instrumentation for Proton Therapy.

Finally, we would like to explore the development of instrumentation for silicon-based radiation detectors. The main line of work is related to the SpaceRad group and the possibility of developing systems to be flown. One of the systems could be based on COTS components to develop low-cost radiation monitors. We have also been involved in tests of the RADEM monitor.

Medium-term (3-5 years) prospects

The infrastructure plans to secure its acquired competence in front-end DAQ and digital electronics, as well as in system integration. In this period the operation of MARTA, as well as contributions to muon tomography and to SWGO will be of key importance. We will pursue a closer connection with the RPC group, developing and implementing DAQ systems for other projects within the RPC group.

Furthermore, we will pursue external collaborations. We have already established contacts with groups interested in using systems similar to the ones we developed, and are contacting the OMEGA group to establish a stronger partnership.

The diversification of the infrastructure activities is now possible, and we will pursue synergies with research groups at LIP to apply 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.

We will also focus on the dissemination of the acquired competences giving support to groups developing electronics at LIP and deploying the developed solutions in several contexts.

SWOT Analysis

Strengths

- The competences acquired in digital logics design and in the design of complex electronic systems.
- Competence in handling several types of detectors such as RPCs and scintillators coupled to photomultipliers or to silicon light sensors.
- Activities developed in the context of research projects. Capability to develop characterization systems.
- Possibility to plan and perform irradiation campaigns.

Weaknesses

- Up to now it was not possible to attract direct financing for detector development.
- The level of funding is incompatible with the full development of detectors.
- Publishing the work developed as independently as possible is an important task yet to be pursued.

Opportunities

- The MARTA Engineering array gives us the opportunity to lead a medium size project from end to end.
- SWGO creates a mid-term opportunity to consolidate activities.
- In the longer term, ATLAS offers the opportunity to consolidate activities on fast and digital electronics.
- The radiation damage studies present the possibility to attract students and funding through the SpaceRad group.
- Training activities, courses lectured at the lab and MSc theses developed in the lab may allow to increase the human resources and allow to pursue different projects.
- The know-how acquired in the laboratory can boost the participation in novel projects related to fast timing and development of instrumentation for medical physics.
- The investment plan resulting from the FCT evaluation allows to increase the test-and-measure capability.

Threats

- Financing is always a key issue when developing hardware that needs investment in service acquisition and materials.
- Lack of humanpower 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

3 Undergraduated Student(s) and Trainee(s):
Diogo Mendonça, Francisco Ferreira, Helene Rehahn

Executive summary

LOMaC was created for the test and preparation of WaveLength Shifter (WLS) fibres for the ATLAS TileCal project in the 1990s. LOMaC's expertise is 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.

Recent work focused on the development of a prototype of a dosimeter with sub-millimetric resolution in collaboration with LIP's Dosimetry group and the e-CRLab, on the radiation hardness of TileCal scintillators focusing on the HL-LHC, and on support for tests of the High Voltage (HV) boards for TileCal upgrade. Research of new scintillating materials for future detectors started in a collaboration with the Institute for Polymers and Composites (IPC) of the University of Minho. Parallel work on maintenance, upgrades, and reinstallation of LOMaC equipment went on and is expected to continue with progress also on the 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 – automated device to characterize sets of up to 32 optical fibres.
- Mono-fibremeter – automated device to characterize individual optical fibres.
- Tilemeter – 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 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.

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 in 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. Since LIP moved to the 3Is unit of the University of Lisbon, we already reassembled most of the equipment at LIP labs in 3Is. 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 (FCC) detectors.

Assessment of the past year: objectives vs. achievements

Despite the negative impact of the COVID-19 pandemic in the lab activities, LOMaC achieved a large fraction of the objectives for 2021.

The recovery of the facilities progressed along 2021, allowing for the first tests of fibre cutting using the lathe. The maintenance of the vacuum pumps of the sputtering machine done at UNL and reinstallation also progressed and the aluminization facility is almost ready to restart operation.

The Tilemeter was improved, with new (and old) PMTs that are still being tested, to help in the construction of the new hodoscope for the measurement of the number of photoelectrons in scintillating fibres and thin scintillators.

Tests of the new TileCal High Voltage system have been done using a single PMT and showed to be more practical to perform in the open lab using oscilloscopes than in the PMT testbench. For this reason the upgrade of the PMT testbench was postponed.

Members of the team participated in the activities promoted by ECFA for the R&D Detector Roadmap discussion, in particular in the Calorimetry and Photon detectors sections. We are involved in the creation of the LIP FCC team and participated actively in the session of FCC Engagement Meeting.

We initiated a new project (DLight) for the development of radiation-harder scintillating materials investigating promising polymer substracts. This is an exploratory project that was financed by FCT to start in 2022. PET (Polyethylene terephthalate) and PEN (Polyethylene naphthalate) polymers will be investigated in collaboration with the Institute for Polymers and Composites (IPC) of the University of Minho. Raw materials were purchased and a first test of extrusion of PET and PEN was performed with the production of a few samples of small plates.

In the framework of the ATLAS TileCal, we studied the radiation damage of the scintillators and WLS fibres. The study used data from the TileCal calibration systems collected along the years of LHC runs. The data analysis and extrapolations for the HL-LHC phase still suffer from large uncertainties. New studies may help to assess radiation damage of the TileCal optics and also in the development of new radiation hard scintillators for future detectors.The aging studies of TileCal optics progressed and included updated simulation of the doses in the cells. Maps of light output degradation were produced for the several cells of the TileCal calorimeter.

The collaboration with the LIP Dosimetry Group and e-CRLab continued for the readout and characterization of scintillating optical fibres for applications in microdosimetry. The first set of modules of scintillating fibres arrays was prepared and polished in the facilities.

LOMaC's contribution to education and outreach this year was constrained by the pandemic situation. Yet, during the LIP Summer Internship Programme, three students have worked at LOMaC for their projects. One student worked on the new high voltage system for the TileCal upgrade, and the other two worked on the development of a new, portable measurement system for scintillation detection to assist the new scintillators production at Minho, and in the first studies for the hodoscope spectrometer to measure the number of photoelectrons.

Lines of work and objectives for next year

For 2022, a boost in the facilities is expected, with the progress in the reequipment program. The LOMaC reequipment program this year is oriented for the test benches at the level of light detection and data taking, and to the finalization of the work to get the aluminization facilities operational.

The tilemeter improvement will continue, with the replacement of the last old PMT by new ones, after testing the PMTs purchased last year. To work closely with the Tilemeter, a new hodoscope for the measurement of the number of photoelectrons in scintillating fibres and thin scintillator plates will be setup using new electronics, including a new fast oscilloscope with the capability to process and store large number of events.

With respect to the aluminization facilities, the lathe is already operational and small improvements will be done. The sputtering equipment is almost ready in the new place and the assembly will be finished. We will restart aluminizations with a bundle of fibres for the NEXT experiment.

Tests of the new TileCal High Voltage system will continue, using oscilloscopes as DAQ systems.

Aging studies of TileCal optics focusing on scintillators and fibres are planned, and new data will be available with the restart of the LHC operations.

In the framework of the DLight project that was funded for 2022/23, the production of new samples of PET/PEN scintillators will be done at the Institute for Polymers and Composites of the University of Minho. These samples will be tested at the LOMaC facilities. This type of scintillators are possible candidates for the refurbishment of the ATLAS TileCal gap/crack scintillators and for future FCC detectors.

The collaboration with the LIP Dosimetry Group and e-CRLab will continue for the readout, preparation and characterization of scintillating optical fibres (isolated and in arrays of juxtaposed fibres) for applications in microdosimetry. A first prototype is expected to be concluded this year.

Medium-term (3-5 years) prospects

In the medium term, LOMaC's contributions will focus on three main 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, since they cannot be replaced.

The second area is to contribute to the development of future scintillator-based detectors. Performance studies of future calorimeters based in simulation are being planned in collaboration with CERN. In terms of detector R&D for the future, we will try to fit our activity into the R&D Detector RoadMap specifications.

The third area corresponds to applications to microdosimetry. After the conclusion of a first prototype, the collaboration with the e-CRLab and the Dosimetry Group will continue aiming for the design and fabrication of an improved version of the microdosimeter.

SWOT Analysis

Strengths

Long 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 LIP Internship Program and the PT-CERN PhD grants started to attract people interested to work in the areas of activity of LOMaC.

Threats

Lack of sustained operations is possible.

RESEARCH INFRASTRUCTURES

TAGUSLIP

TagusLIP laboratory

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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 startups and SMEs.

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, office 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. 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 (DAQ) of the Electromagnetic Calorimeter (ECAL) 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 PETsysElectronics.

Benefiting from the infrastructure available at TagusLIP, PETsys Electronics was able in the past 8 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.

Assessment of the past year: objectives vs. achievements

In 2021 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:

LIP CMS group

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. The results with the first two prototypes TOFHIR2A and TOFHIR2X showed excellent performance matching the simulation expectations. A batch of test boards of TOFHIR2X was produced, tested and made available to several groups in the CMD/MTD collaboration. The TOFHIR2X Test Board was integrated with sensor modules (LYSO crystals coupled to SiPMs) and tested successfully in a proton beam at CERN in October 2021.

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. In the end of 2021, the new FE_v2 boards have been integrated in the prototype of the BTL Readout Unit at CERN. The validation of the complete readout chain will be pursued in 2022.
The results obtained were presented at several international conferences, including IEEE/NSS/MIC 2021 (online conference).

PETsys Electronics

1. Organization of the production, testing and supply of PETsys Electronics products, and development of the dedicated electronics systems for several clients.

2. Microelectronics design of the TOFHIR2X ASIC following the specifications of the LIP-CMS group in the frame of the Collaboration Agreement KN436/EP between LIP and CERN. PETsys Electronics is responsible for the ASIC design and the LIP-CMS group develops the integration of the chip in detector modules. The second version of the chip with improved performance (TOFHIR2X) was submitted for fabrication in November 2020. Due to delays in production originated by the COVID-19 pandemic, the testing started in July 2021. The design of the final version of the chip (TOFHIR2B) was concluded and submitted for fabrication in November 2021.

3. Leadership of the consortium Time-of-Flight PET for Proton Therapy (TPPT) and development of the readout system.

Lines of work and objectives for next year

The LIP-CMS group and the company PETsys Electronics will be the main users of the TagusLIP Laboratory in 2022.

LIP-CMS group

The R&D activities in the CMS Barrel Timing Detector (BTL) planned by the LIP-CMS group are described elsewhere in this report and summarised here:

a) Tests of the second prototype of the BTL Front-End board (FE_v2) with the TOFHIR2X ASIC in the frame of the BTL Readout Unit validation at CERN.

b) Test of the new ASIC version TOFHIR2B designed by PETsys Electronics. Integration with detector modules based on LYSO crystals and SiPMs and characterization with laser light and radioactive sources. The tests with sensor modules are foreseen at TagusLIP and CERN (test beam).

c) Development of the production test systems of the TOFHIR2 chips in BGA package (15 000 chips) and of the Front-End Boards (5500 boards) and organization of the final production of TOFHIR2 BGAs and Front-End Boards for the experiment.

d) Development of prototypes of timing detectors for the future PPS detector at HL-LHC in synergy with the MTD project.

PETsys Electronics

The activities of PETsys Electronics in 2022 include:

1. Tests of components and systems supplied by PETsys Electronics.

2. To pursue the development of the dedicated electronics systems for several clients.

3. To pursue the activities in the Consortium TOF-PET for Proton Therapy, which was funded for the development of proton therapy on-line monitoring. PETsysElectronics is the leader of the consortium and has the responsibility to develop and supply the readout and data acquisition systems of the new in-beam PET scanner.

4. To pursue the development of an improved version of the TOFPET ASIC and of a prototype ASIC for LIDAR.

Medium-term (3-5 years) prospects

In the next three 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.

The PETsys startup company will continue to rent space in TagusLIP. Extrapolating from the present growth of the company it is likely that in the future increased accommodation space will be needed.

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

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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 and laboratories. Besides the hardware and respective firmware, the group also develops the 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

During 2021, the CCMC activities/achievements included:

1. Supervision of three master students, one in collaboration with the industry (Bosch Aveiro) in the following areas, respectively

- Development of a non invasive temperature monitoring device with image/target recognition.
- Development of Machine Learning Tools for the extraction of behavioral and physiological parameters of nesting birds in their natural environment.
- Development of embedded systems for heating, ventilating and air conditioning (HAVAC) and machine learning in microcontrollers.

2. The CCMC recruited two additional students who, given the subject of their theses, are currently doing a joint master's degree between the LZ project (Dark Matter group) and the industry (Active Space Technology).

3. Outreach activities:

- Live presentation of the electronic eggs developed by the CCMC for monitoring the heart rate of nesting seagulls at the 2021 European Researchers' Night.
- Development of an interactive card game, commissioned by MARE. The game was presented at the 2021 European Researchers' Night and can be adapted to other research fields.

4. Participation in the Summer Internship Program for undergraduate students at the University of Coimbra and LIP with the projects:

- "Observation of cosmic muons" (3 students).
- "Non invasive temperature monitoring device" (3 students).

5. The CCMC applied for FCT funding with two projects ("Do really some like it hot? Effects of heat stress in avian reproduction" and "Restoring curiosity at the heart of science communication: particle physics as a case study" in collaboration with the MARE-ECOTOP and LIP-ECO groups respectively), with none being selected for funding in spite of their evaluation, due to an highly competitive call.

6. Implementation of the temperature control software for the RPC modules installed in the HADES experiment.

7. The work on the CCMC end-user software framework continued in collaboration with the LZ LIP group but was not yet completed doe to the lack of human resources.

8. The environment monitoring system planned for the server room at LIP-Coimbra was not installed due to the lack of human resources.

Lines of work and objectives for next year

The main objectives for 2022 are:

1. We plan to apply for funding again in a partnership with MARE-ECOTOP. The project, still under assessment, aims to develop tools to infer the impact of climate changes in the nesting of birds.
2. Build an autonomous cloud chamber with real-time identification of particle tracks for outreach activities. The instrument made of low-cost materials will be available for sale to the public, namely schools.
3. Finish the end-user software framework currently being developed in collaboration with the LZ LIP group. This work, which merges a Graphical User Interface (GUI) developed by the LZ team with the database tools developed within the CCMC, intends to be the base of the software solution for a general purpose monitoring tool with applications both in research and industry.
4. Continue to invest in the development of 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 MSc students in industry, as it also represents a privileged vehicle to disseminate our capabilities aiming at future collaborative projects.
6. Expect to hire a new collaborator (0.5 FTE) to get involved in the technical work of the ongoing activities and perform market prospection for the production of an optimized CCMC portfolio.

Medium-term (3-5 years) prospects

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. In the medium-term period, the vehicles to achieve this objective will be:

1. Creation of a portfolio to disseminate information on CCMC competencies.
2. Continue to invest in the training of human resources in collaboration with industry, as it represents a privileged vehicle to look for new project opportunities outside the academy.

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 (explicitly) allocated FTEs or resources for the procurement and project development and integration with the other LIP infrastructures.
- 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 possibile inability 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)

- *"Non Invasive Temperature Monitoring Device"*, Daniel Sousa and Miguel Roldão, LIP-STUDENTS-21-15

Presentations

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

- Afonso Ávila; Daniel Coelho and Julio Santos: *"Muões num balão: medidas do fluxo e muões até à estratosfera"*, 2021-09-13, ,

Theses

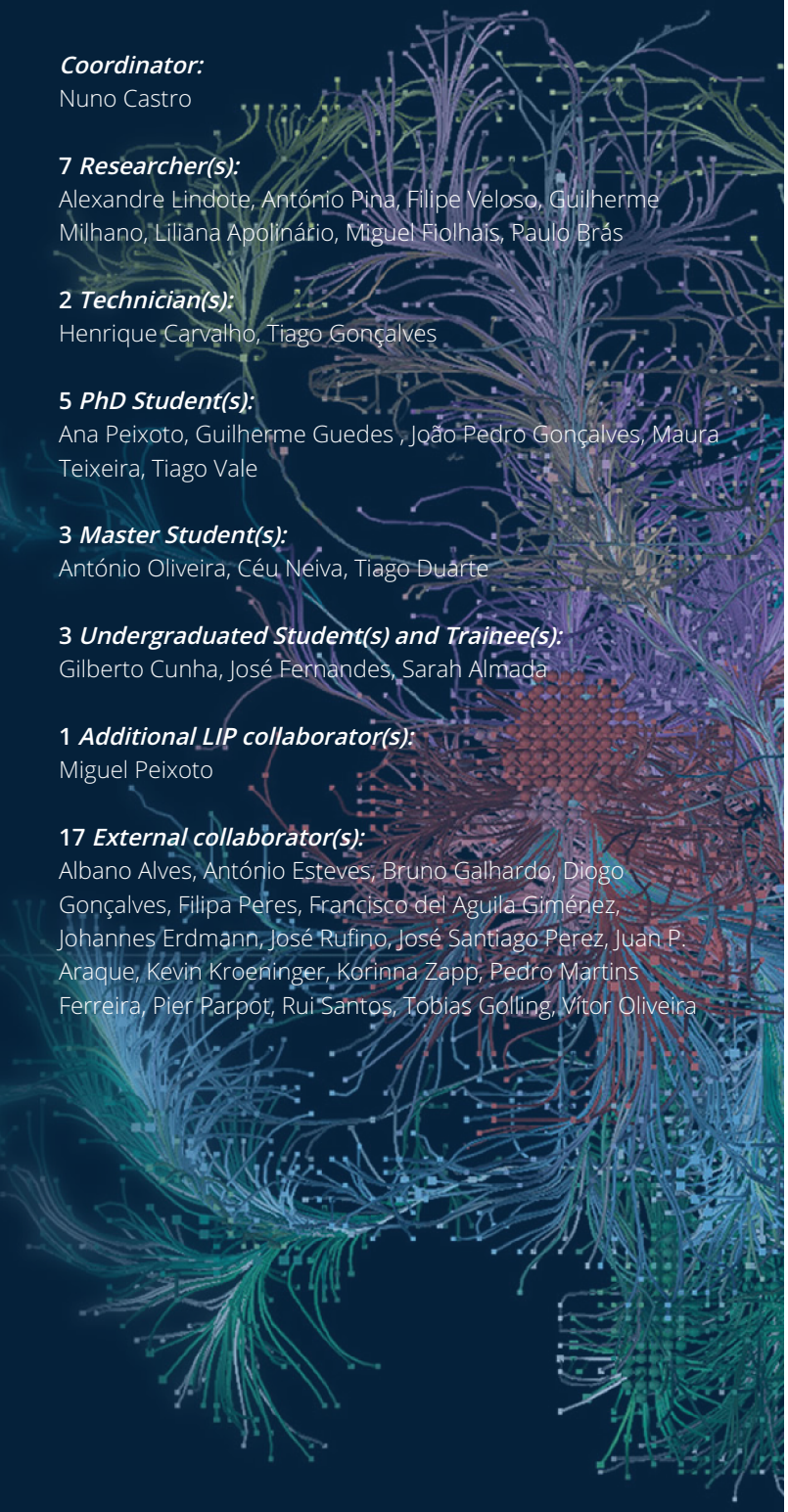
3 Master

- João Parente: *"Development of Machine Learning Tools for the extraction of behavioral and physiological parameters of birds in their natural environment"*, 2017-09-01 , (ongoing)
- José Rodrigues: *"Embedded systems for heating and machine learning in microcontrollers"*, 2021-09-01 , (ongoing)
- Rita Barradas: *"Non invasive temperature monitoring device"*, 2021-09-01 , (ongoing)

COMPETENCE CENTERS

SIMBIGDAT

Competence Centre on Simulation and Big Data



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Executive summary

The purpose of the SimBigData CC 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 academy and industry. The LIP groups have a vast range of competences in data analysis and simulation tools, including physics models, Monte Carlo generators, detector simulation tools, big-data handling techniques and data mining. The ability to fully benefit from such competences requires achieving critical mass, a coordinated training program, the exploitation of synergies and a clear identification of the key areas in which we can contribute in a competitive way.

The CC started its activities almost three years ago, with a significant boost since 2019 when dedicated human resources were hired through a funded project. The project was successfully finished in 2021, and the achieved critical mass allowed us to continue the activities. A new exploratory project devoted to quantum machine learning was obtained in 2021. For the simulation part, the specific contributions to the GEANT4 collaboration are central for the CC, as well as the training of students and researchers in simulation and machine learning.

As for the 2021 activities, 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; Active participation in the GEANT4 collaboration, with development and support responsibilities by LIP members; Support to the specific needs of LIP research groups; Simulation of the space radiation environment, in the context of the LIP SpaceRad group.

On the Big Data side, in 2021 the BigDataHEP project was successfully concluded. Several publications and theses were completed and a follow-up project, dedicated to the use of deep learning techniques for anomaly detection in HEP data is being prepared. A new exploratory project, devoted to quantum machine learning was started. A new collaboration with the Center of Physics of UMinho, devoted to the use of machine learning techniques in condensed matter physics, led to a new funded project. The collaboration with Tellspec on the use of portable, near infrared spectrometers for quality control in industrial production lines was continued, in collaboration with the Center of Chemistry of UMinho. Some team members succeeded in their application to CPU and GPU hours in the second edition of a national call for access to scientific computing clusters.

SimBigDat

Overview

The purpose of the Competence Center on Simulation and Big Data is the fostering of 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 academy and industry.

The different LIP groups have a vast range of competences in data analysis and simulation tools, including physics models, Monte Carlo generators, detector simulation tools, big-data handling techniques 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 CC thus has two independent, although interconnected branches of activity:

- Simulation: For the simulation part, in these first few years the common activities have been very much centered, altough not exclusively, on GEANT, which is a common ground to many groups. The work in this area and the specific contributions to the GEANT4 collaboration should be continued and expanded
- Big Data: On the big data part, the team is consolidating the experience on anomaly detection techniques in experimental contexts where uncertainties play an important role. 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.

The competence center started its activities almost three years ago, with a significant boost since 2019 when dedicated human resources were hired through a funded project. The main funded project of the Competence Center was successfully finished in 2021, but the achieved critical mass allowed us to continue the activities. A new exploratory project devoted to quantum machine learning was obtained in 2021.

More details on the 2021 activies and on future prospects are given below.

Assessment of the past year: objectives vs. achievements

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. An introductory talk on Detector Simulation was given in the context of the 2021 LIP Summer Internship Programme.
- In the context of undergraduate courses, further developments to the GEANT4-based virtual laboratory were undertaken. This tool has been quite useful as a way of complementing and helping the understanding of the results obtained in radiation physics laboratory courses.
- Participation in the GEANT4 collaboration was continued. Support and maintenance of the Advanced Example LIP is responsible for was continued, namely in view of the latest GEANT4 release.
- Support to the specific needs of LIP research groups was continued.
- The simulation model of the radiation environment on Mars (dMEREM - detailed Martian Energetic Radiation Environment Model), developed at LIP by the Space Radiation Environment and Effects group in the framework of a contract between ESA and an international consortium has been validated with real data from the Radiation Assessment detector at Mars surface. The results were submitted to a peer-reviewed journal and are accepted for publication. In addition, dMEREM was modified to provide flux measurements below the surface. The Ambient dose equivalent and the effective dose that can be measured at Mars surface and underground were calculated.
- The planned second edition of the introductory course on GEANT4, was postponed due to the continuing limitations imposed by the pandemics.

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, resulting in 4 publications, 2 completed MSc thesis (2 ongoing) and 2 completed PhD thesis (3 ongoing). The work developed within the Competence Centre, in collaboration with groups at LIP and beyond, was presented in workshops and international conferences.
- Organization of the 3rd School and Symposium “Data Science in (Astro)Particle Physics and Cosmology: the Bridge to Industry”, foreseen to Coimbra in 2020 had to be postponed. It is now foreen for June 2022.
- The partnership with Tellspec, in the context of the analysis of data collected with portable infrared spectrometers and possible applications to quality control in production lines, was continued.

- Ongoing collaborations between members of different LIP groups (ATLAS, CMS, Auger, SWGO, Dark Matter, Pheno, SHiP) in the context of machine learning.
- 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.
- Start of a new exploratory project, funded by FCT, on the study of the use of quantum computers for machine learning applications in the context of HEP and beyond.

Lines of work and objectives for next year

The Simulation branch of the CC will continue its contribution to the teaching of advanced detectors' simulation methods at graduation and doctoral programs. The participation in the GEANT4 collaboration will be continued as well as the support to the needs of the LIP groups. A second edition of the Introductory course on GEANT4 will likely be held.

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, 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 in ATLAS and in the search for rare events in LZ. The dissemination of this work in the experimental collaborations will be continued and expanded.

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 CC.

Medium-term (3-5 years) prospects

The medium term strategy of the SimBigData 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 data handling.

The main challenge for the CC is its consolidation in an extremely competitive area, following the plan defined at its creation, more than three years ago: to expand LIP's competences in this area by exploiting synergies between the groups, implement a training program and establish partnerships with the academic and industrial communities. 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 data mining techniques used beyond HEP.
- Integration in international collaborations.
- Diverse team, consolidated by competitive fundings secured by the Competence Center.

Weaknesses

- Despite some progress in the last years, the efforts ongoing at LIP in this field are not yet fully integrated.
- 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.

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).
- A new proton therapy facility in Portugal may open new opportunities in simulation and data handling.
- The technological line of the PT-CERN grants programme can allow PhD students developing work in this area.

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

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

- *"Finding new physics without learning about it: anomaly detection as a tool for searches at colliders"*, M. Crispim Romao, N. F. Castro, R. Pedro, EPJC 81 (2021) 27
- *"Use of a Generalized Energy Mover's Distance in the Search for Rare Phenomena at Colliders"*, M. Crispim Romao, N.F. Castro , J.G. Milhano, R. Pedro, T. Vale, Eur. Phys. J. C 81, 192 (2021)
- *"A continuous integration and web framework in support of the ATLAS Publication Process"*, Juan Pedro Araque Espinosa, Gabriel Baldi Levcovitz, Riccardo-Maria Bianchi, Ian Brock, Tancredi Carli, Nuno Filipe Castro, Alessandra Ciocio, Maurizio Colautti, Ana Carolina Da Silva Menezes, Gabriel De Oliveira da Fonseca, Leandro Domingues Macedo Alves, Andreas Hoecker, Bruno Lange Ramos, Gabriela Lemos Lúcidi Pinhão, Carmen Maidantchik, Fairouz Malek, Robert McPherson, Gianluca Picco, Marcelo Teixeira Dos Santos, JINST 16 (2021) T05006
- *"Deep Learning for the Classification of Quenched Jets"*, L. Apolinário, N. F. Castro, M. Crispim Romão, J. G. Milhano, R. Pedro, F. C. R. Peres, JHEP11 (2021) 219

2 International Conference Proceedings

- *"Deep Learning Versatility in New Physics Searches"*, Miguel Romão, PoS (ICHEP2020) 233
- *"Getting the public closer to the experimental facilities: How Virtual Reality helps High Energy Physics experiments engage public interest"*, Ana Peixoto et al., PoS ICHEP2020 (2021) 954

Presentations

2 Oral presentations in advanced training events

- Bernardo Tomé, Liliana Apolinário, Patrícia Gonçalves: *"Detector and physics simulations"*, 2021-07-07, LIP Internship Program 2021: LIP Summer Internship Program 2021, Online
- Nuno Castro: *"Probing the Standard Model and Beyond at the LHC"*, 2021-07-15, 6th Lisbon mini-school on Particle and Astroparticle Physics, online

1 Seminar(s)

- Nuno Castro: *"Search for vector-like quarks at the LHC"*, 2021-04-22, CFTP Seminar, online

1 Outreach seminar(s)

- Nuno Castro: *"À procura do inesperado em física de partículas: como encontrar uma agulha perdida em muitos palheiros"*, 2021-03-24, Programa O Melhor Estudante na UMinho, online

Theses

5 PhD

- Ana Peixoto: *"Search for new interactions in the top quark sector"*, 2016-09-13 / 2021-09-13, (finished)
- Tiago Vale: *"Search for heavy fermions with LHC data"*, 2016-09-13 / 2021-10-24, (finished)
- Guilherme Guedes: *"Collider and astrophysical constraints to little Higgs models"*, 2018-11-13 , (ongoing)
- Maura Teixeira: *"Searching for dark matter with the ATLAS detector using unconventional signatures"*, 2021-01-01 , (ongoing)
- João Pedro Gonçalves: *"Disentangling and Quantifying Jet-Quenching With Generative Deep Learning"*, 2021-09-01 , (ongoing)

4 Master

- Tiago Duarte: *"Treino de redes neuronais profundas de forma distribuída"*, 2018-10-01 / 2021-03-31, (finished)
- Tiago Gonçalves: *"CoR-HPX - Uma nova abordagem à computação orientada ao recurso"*, 2019-10-01 / 2021-05-28, (finished)
- António Oliveira: *"Unsupervised machine learning techniques in high energy physics"*, 2020-09-08 , (ongoing)
- Céu Neiva: *"Advanced machine learning techniques in rare events research at the Large Hadron Collider"*, 2020-09-01 , (ongoing)

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Nuno Castro	Guilherme Milhano	239.990 €	2018-07-01 / 2021-06-30	PTDC/FIS-PAR/29147/2017, POCI/01-0145-FEDER-029147 / BigDataHEP: Understanding Big Data in High Energy Physics: finding a needle in many haystacks
Nuno Castro		18.750 €	2022-01-01 / 2024-12-31	PTDC/FIS-MAC/2045/2021 / Excitações em materiais quânticos 2D/INL (Participation in UMinho project)
Miguel Romão	Inês Ochoa	30.000 €	2022-02-01 / 2024-01-31	CERN/FIS-COM/0004/2021 / QML-HEP_Explorando a aprendizagem de máquina quântica como uma ferramenta para colisionadores de altas energias presentes e futuros

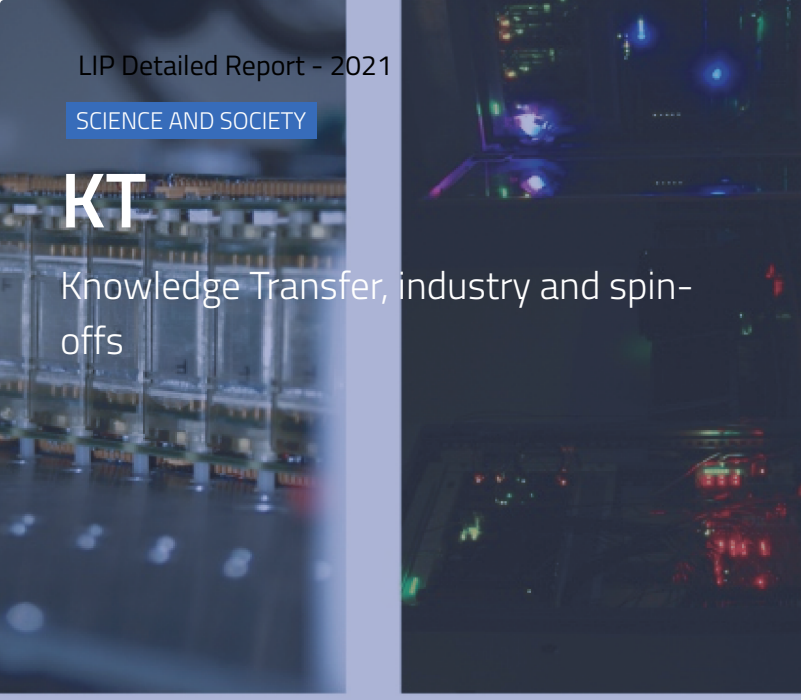
Science and Society

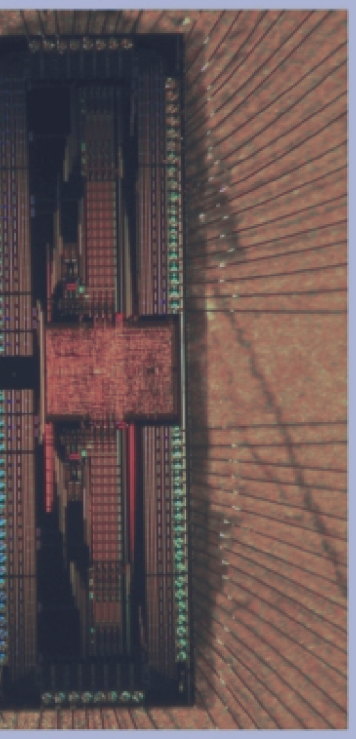

KT Knowledge transfer, industry and spin-offs
AT Advanced training
RHE Radiation, Health and environment
ECO Education, Communication and Outreach
MuTom Muon Tomography

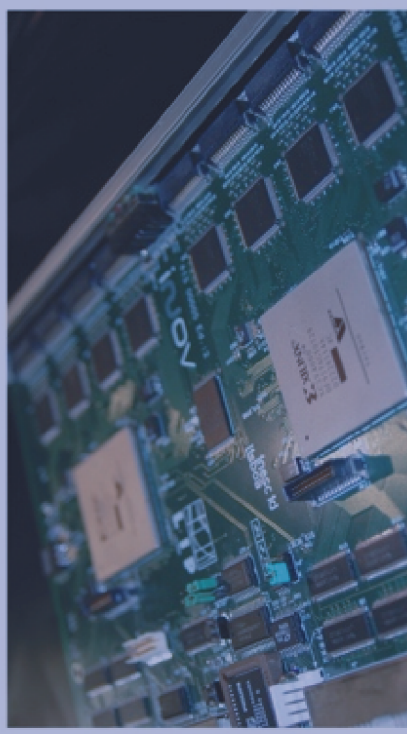
SCIENCE AND SOCIETY

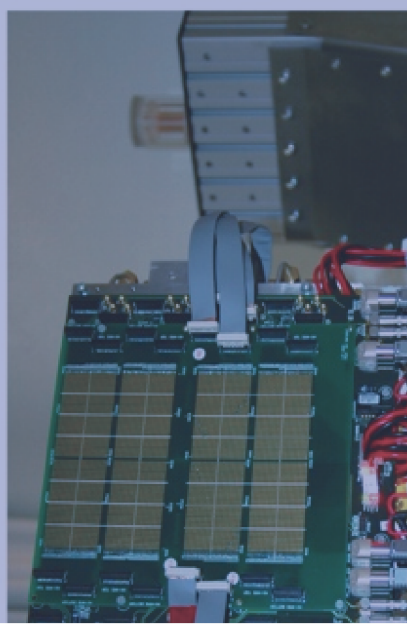
KT

Knowledge Transfer, industry and spin-offs









Executive summary

LIP is engaged to specific objectives that support public policies in several sectors. In the last few years, LIP has made impactful contributions by developing excellent fundamental and applied research; attracting talent; bridging scientific knowledge and business innovation; developing diagnosis and therapy methods; focusing on science and technology culture and education, supporting the school community; promoting digital competences and technology accessibility towards social inclusion; and contributing to increase computing power and expertise in environment-related research and in the scientific community at large.

LIP's experience in common projects with companies and with other research units must be used to leverage its innovation impact within our fields of expertise, namely through collaborative projects with companies and other external entities, in consortia of various dimensions. As CERN's reference institution in Portugal LIP has a special role in promoting the internationalization of Portuguese companies, including in the training dimension.

The list of companies the LIP groups have collaborated with in the last few 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, CFTC/FCUL, CFTP/IST, CHUC, CTN/IST, FCCN/FCT, GHIPOFG, Hospital de Santa Maria, IBEB/FCUL, ICNAS, INCD, INEC-ID, INESC-TEC, LNEC, MACC, MARE. LIP has direct links with Scientific Infrastructures included in the National Roadmap.

In line with the Portuguese and European strategy to increase the digital competences and technologies, LIP will continue and expand its leadership role and its several contributions to the national infrastructures for information and communication technologies and to their integration in European networks. LIP represents Portugal in several international forums addressing links to society: CERN KT for medical applications, HEPTech, Teacher and Student forum, European Particle Physics Communication, International Particle Physics Outreach Group (co-chaired by LIP), and several European computing infrastructures and initiatives.

In the coming years our KT and public policy support objectives will be pursued and supported by LIP structures.

KT

Overview

LIP is engaged to specific objectives that support public policies in the science, health, economy, social and environmental sectors. In the last few years, LIP has made impactful contributions by developing excellent fundamental and applied research; attracting talent; bridging scientific knowledge and business innovation; developing diagnosis and therapy methods; focusing on science and technology culture and education, supporting the school community; promoting digital competences and technology accessibility towards social inclusion; and contributing to increase computing power and expertise in environment-related research and in the scientific community at large.

The list of companies the LIP groups have collaborated with in the last few 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, CFTC/FCUL, CFTP/IST, CHUC, CTN/IST, FCCN/FCT, GHIPOFG, Hospital de Santa Maria, IBEB/FCUL, ICNAS, INCD, INEC-ID, INESC-TEC, LNEC, MACC, MARE.

LIP's experience in common projects with companies and with other research units must be used to leverage its innovation impact within our fields of expertise, namely through collaborative projects with companies and other external entities, in consortia of various dimensions. Strategic areas are healthcare, space application, data science and digital technologies. Both national and international collaborations will be established, namely in the context of the Strategic Infrastructures that LIP is connected to and of international collaborative funding programmes, such as the ones with US universities (e.g. Portugal-Austin).

As CERN's reference institution in Portugal and recognised partner of ESA and of PT Space, LIP will maintain a close partnership with the Portuguese Industrial Liaison Officer (ILO) for CERN and with ESA's Industrial Policy Committee (IPC) representative at PT Space. This has been a successful way to promote the internationalization of Portuguese companies in the past and it will be strengthened by proposing partnerships, providing support or facilitating a first contact. LIP is a member of the PERIN and will actively develop efforts to strengthen the collaborations with this network.

LIP keeps a close connection with the representative of Portugal in the CERN KT forum (José Antão, from ANI), in the CERN KT forum for medical applications (Paulo Crespo, from LIP) and HEPTech, an European Network devoted to KT from large scale HEP science projects and research facilities (José Carlos Silva, from LIP). Such forums will be further explored with the goal of increasing the industrial return to Portuguese institutions.

LIP has direct links with Scientific Infrastructures included in the National Roadmap: LIP is the technical coordinator of the National Distributed Computing Infrastructure (INCD); LIP is a founding member of ProtoTera; LIP is the main technological partner in several projects of the National Brain Imaging Network (BIN); LIP is committed to work with the Portuguese Space Agency (PT Space), reinforcing its projects with ESA and with national and international industrial and academic entities. The areas of healthcare applications, space exploration applications, and information technologies have the potential to improve both the quality of life (reinforcing the quality of health, education and research networks) and the economy (improving the competitiveness of Portuguese companies).

In line with the Portuguese and European strategy to increase the digital competences and technologies, LIP will continue and expand its leadership role and its several contributions to the national infrastructures for information and communication technologies and to their integration in European networks. Dedicated training programmes will continue to be organized, following the ongoing efforts, such as the Data Science School and Symposium, organized by LIP since 2018 and involving a growing number of organisations ranging from academia to the corporate sector. Technical and ethical aspects will be the focus of such training, with the involvement of the LIP Computing and IT group, the competence centre on Simulation and Big Data and the Social Physics and Complexity group, in coordination with the Advanced Training (AT) and ECO groups. The focus will be on the area of competences of LIP and the current partnerships will be expanded to enlarge the impact of these activities. LIP's international contacts, in particular our international scientific partnerships and our network of contacts in Portuguese speaking countries will allow us to enlarge the different types of public engaged in the training programmes at the different levels.

In the coming years our KT and public policy support objectives will be pursued and supported by LIP structures: research infrastructures, Competence Centres, Advanced Training and Education and Outreach groups. Nevertheless, the existence of a dedicated KT group, or at least of a KT coordinator, would be highly desirable for the lab. The KT group/coordinator, would keep track of technological R&D within LIP's groups, actively search for calls and opportunities, in close connection with LIP's Support to Users and Projects team.

SCIENCE AND SOCIETY

RHE

Radiation, health and environment

Coordinator:
Luis Peralta (30)

6 ***Researcher(s):***
Alina Louro (10), Conceição Abreu (30), Florbela Rêgo (10), Joaquim Pedro Kessongo (54), Sandra Soares (80), Yoenls Bahu (89)

2 ***External collaborator(s):***
Diogo Almeida, Patrick Sousa

Total FTE
3.0

Executive summary

The main activity of the group are radon measurements. The group has been involved in radon surveys in Portugal (in the Guarda district) and Angola (in Bíbala and Huíla districts) where radon concentration in water and in air have been measured. The radon exhalation from Portuguese granite construction has also been evaluated and this line of research is going to be pursued in the future. The group has been involved in several workshops and training activities with high school and university students on radon issues awareness.

RHE

Overview

The group main laboratory for radon studies is the LabExpoRad in Covilhã. The facility is integrated in UBIMedical, the University of Beira Interior (UBI) health technology park. The laboratory is equipped for the detection of radon in water and air. Developments for radon detection as been carried out in the Lisbon laboratory at the Faculty of Sciences of the University of Lisbon (FCUL). In the past few years the work focus was the measurement of radon in air and water in Angola. The study of radon exhalation from local granite samples was also performed. The characterization of gamma background at the UBI faculty building was made.

Assessment of the past year: objectives vs. achievements

1. Radon measurements

The exposure to radon in buildings in the municipality of Lubango, Angola, during winter months was performed and the data analyzed. The results have been published and a PhD thesis on the subject was successfully concluded during 2021.

2. Radon exhalation

Radon mass exhalation rate is one of the parameters commonly used to quantify indoor radon release from building and ornamental materials. This quantity can be obtained from the radon concentration in air. The measurement techniques rely on the so called Closed-Can method. This method consists in placing the sample to be measured inside a sealed chamber and measure the radon concentration after a time interval. The chamber radon-tightness is an important issue, as we demonstrate in previous work. A new, improved chamber has been built in collaboration with the Department of Mechanical Engineering of UBI and its performance is under study. Also, commercially available low-cost chambers have been considered. A system based on the low-cost radon detection system developed by our group has been used to monitor the chamber radon leakage. This is a work in progress.

3. Gamma background assessment

The measurement of the gamma background due to the presence of radioactive nuclides in the building materials of the Physics Department of UBI building was made and compared with the same measurement made at the CTN premises in Sacavém. Without surprise, a higher gamma background was recorded at UBI.

4. Potassium content in concrete

Concrete contains sand, which depending on its origin might have a high content in potassium. A method to assess the radiation activity per unit area due to radioactive potassium in the floor slab has been developed. The essay conducted in the FCUL laboratory produced meaningful results.

5. Effect of aerosols containing radon on the development of aromatic plants

The objective is to analyse the effects and potential consequences on the biological development of aromatic plants exposed to different concentrations of radon. The biological effects of polluted atmospheres, with different concentrations of radon, was assessed using scanning electron microscopy techniques for the morphological analysis of the leaf surface and energy dispersive X-ray spectroscopy, for the analysis of the chemical elements existing in the plant.

Lines of work and objectives for next year

1. The assessment of indoor air quality - NORM. This work carries out radon exhalation tests of granite from different sources, common in indoor environments. The goal is to obtain a catalog of granitic materials of low radon exhalation.

2. The group participates in a national network for environmental radiation measurement, and focus its activity in the measurement of natural gamma emission from building materials and radon exhalation.

3. More testes on the effect of aerosols containing radon on the development of aromatic plants are scheduled for 2022.

4. The group continues to participate in several student training activities.

5. Cooperation partnerships in higher education:

The project concerns the Blended and Remote teaching Activities supported by Virtual rEality for Radiation sciences (BRAVER). The goal of this strategic partnership is to increase the knowledge sharing in radiation protection and safe use of radiation sources across European countries. To achieve this, the project aims at improving the blended learning activities with new innovative educational approaches that enable and stimulate collaboration and can adapt quickly to current difficult circumstances using E- and M-learning combined with a safe offering of practices. However, special attention is needed for the development of soft skills using digital education not only from the point of view of competences but

also for the well-being of students. Bearing in mind this aspect, the current project aims to develop blended and remote teaching approaches in the form of educational collaborative games that are embedded in a strong learning environment.

Medium-term (3-5 years) prospects

1. Strengthen the institutional relation with Agência Portuguesa do Ambiente (Portuguese Environmental Agency) in the framework of a national network for natural radiation monitoring.

2. Participation in the Higher Education project "Train the trainees - Train future trainers in radiation protection and nuclear technology". The project results from an application to the ERASMUS PLUS program and is developed in a window of technology and protection against radiation, through the design of interactive distance teaching modules and presence / laboratory modules.

3. Study of stem cells from mice exposed to radon-containing atmospheres and study of the biological effects caused on aromatic plants, used for human consumption, when exposed to atmospheres saturated with radon.

SWOT Analysis

Strengths

Well equipped laboratory.

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

Publications

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

- *"Exposure to radon in buildings in the municipality of Lubango, Angola, during winter months"*, Y. Bahu, J. Kessongo, Luis Peralta and S. Soares, J. Radioanal. Nucl. Chem. 327 (2021) 635-642

2 International Conference Proceedings

- *"The "train the future trainers program, a way to include soft and technical skills in a blended learning program"*, I. Gerardy, S. Schreurs, D. Mostacci, L. Tinova, J. Rodenas, S. Soares, U. Scherer, S. Economides, Proceedings ETRAP 2021 | SCK CEN-BA-152 | SCK CEN/42883176 - pp 25-32
- *"AVALIAÇÃO DO RISCO DO RADÃO PRESENTE NA ÁGUA POTÁVEL DO MUNICÍPIO DA BIBALA"*, J. Kessongo, Y. Bahu, L. Peralta, S. Soares, A FÍSICA PARA O DESENVOLVIMENTO EQUILIBRADO: UM CONTRIBUTO, 3ª. Conferência de Física de países de língua portuguesa - São Tomé, 30 de maio a 1 de junho 2019

Presentations

1 Seminar(s)

- Sandra Soares: *"Radioecologia"*, 2021-01-08, Seminário da unidade curricular Introdução às Ciências Biomédicas - 1º Ciclo em Ciências Biomédicas, Universidade da Beira Interior, Covilhã

Theses

2 PhD

- Joaquim Pedro Kessongo: *"O Potencial da Concentração de Radão na Água do Município da Humpata-Angola: Implicações no Consumo Público"*, 2016-11-01 / 2021-06-08, (finished)
- Yoenls Bahu: *"Avaliação do Potencial de Exposição ao Radão em Edifícios Públicos no Município do Lubango"*, 2016-11-01 / 2021-11-12, (finished)

SCIENCE AND SOCIETY

MUTOM (*)

Muon Tomography

Coordinator:
Sofia Andringa (11)

7 Researcher(s):
Alberto Blanco (3), Bernardo Tomé (3), Lorenzo Cazon (9), Marco Alves Pinto (3), Mário Pimenta (4), Pedro Assis (3), Raul Sarmento (6)

2 Technician(s):
João Saraiva (3), Luís Lopes (3)

2 PhD Student(s):
Luís Afonso (5), Pedro Teixeira (21)

2 Additional LIP collaborator(s):
Magda Duarte (21), Paolo Dobrilla (11)

7 External collaborator(s):
Bento Caldeira, José Borges, João Costa, João Matos, Mourad Bezzeghoud, Rui Oliveira, Vanessa Pais

Total FTE:
0.9

(*) The FTEs listed for 2021 reflect the fact that funding was approved in 15/10/2021

Executive summary

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. This follows on efforts and support by the RCP R&D, Auger, SWGO and ECO groups, with people from the three LIP nodes: we explore an existing muon telescope made with autonomous RPCs and low power electronics, developed for the Auger MARTA project.

The LouMu project is done with partners from the Earth Science Institute (ICT), at the University of Évora, and the Ciência Viva science center at Lousal (CCVL), that houses an underground mining gallery. The interface areas will be subject of two PhD theses, one focusing on the use of particle physics for geophysics (coincident with the LouMu main goals), another on science communication (focusing on cosmic ray and muography museum modules). Younger students have successfully joined the team after summer internships at LIP.

The telescope is made of 4-RPC planes, that can be easily exchanged as R&D on RPCs continues. The planes of 1 m² are mounted horizontally in a movable structure, that can be tilted up to 30º. The center of the planes has a high and regular pixelization, while the rest of the area is shared by pixels with different shapes and sizes for optimization of the RPC+FEE readout. The default configuration, a resolution of ~3º is achieved in a 30º field of view, matching our initial goals. These aperture and resolution can be changed by adjusting the distance between planes. After commissioning and optimization of the telescope, a few % accuracy is achieved in the contrast of the muon transmission images.

In 2021, the telescope was optimized at the Laboratory, and a campaign was started to muograph a part of the building where it was located in Coimbra. By the end of the year, we had the muon transmission maps constructed, and data had been taken and shown next to the telescope and online, so that the telescope could be operated almost as a photographic camera.

In 2022, the telescope will be moved to the underground gallery in the Lousal mine, and the geophysical survey will be started. The basic tools are the image reconstruction and a full simulation against which to compare. But 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

The LouMu project has a short-term funding, setting a relatively tight schedule for demonstrating the capabilities of the telescope and 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 preparation of the telescope, including mechanics, RPC detector and readout are guaranteed by the team members at LIP-Coimbra; the analysis, including the response of the RPC and the image reconstruction, is done mostly at LIP in Minho and Lisbon; the simulation is shared between Lisbon and Évora, as will be the geophysical analyses tools; the communication effort is shared between LIP-Lisbon and Lousal.

The analysis of the muography data in the Coimbra building is done with a simple step modeling of the flux, attenuation, and detector response; but this is not enough to impact in geophysical surveying. ICT is surveying the surroundings with other geophysical techniques; this will allow for a more realistic GEANT4 model against which to compare the first data, and will later be used to constrain the geological model inversion, as usually done for geophysical interpretation.

The project has a strong component of education, communication and outreach. All its phases are shared with the public, namely in search for future more generalized use of muon tomography.

Assessment of the past year: objectives vs. achievements

Optimization of Detector and Image in Coimbra, focusing on high resolution central field of view:

- the muographic images were optimized to ~5% by equalizing the electronic response of the inner high granularity channels and correcting for the detector spacial dis-uniformity, at the laboratory.
- the telescope was prepared to be moved and a first muographic campaign was conducted, imaging from different points the building in Coimbra, with automatic construction of the images.

Preparation of the tools for geophysical muographic surveying, focusing on the analyses at Lousal:

- new geological targets and data were added to GEANT4 simulation of muon propagation.
- the simulation was interfaced with the detector model, validated with data from Coimbra.
- this is used to prepare the survey at Lousal and as reference for transmission measurements.

Education, Communication and Outreach:

- two posters introducing the LouMu projects are now in display at Lousal, introducing cosmic rays, particle detection and muography. One of them at the main entrance and the other installed next to a small prototype telescope used previously to test the logistics in the gallery.
- the project webpage was enlarged and put online, it shows the several work lines and also the images as being taken at each moment by the telescope (now in Coimbra, later at Lousal).

Lines of work and objectives for next year

The telescope will be installed at Lousal during the first semester of 2022. Focus will move to interfacing particle physics and geophysics techniques and analysis methods. At the same time, the data acquired in the building will be fully exploited in terms of imaging capabilities and detector R&D. Efforts on communication will be increased at Lousal and in search for future uses of muography.

A few, non-critical, items should be solved before moving to Lousal:

- at present the data acquisition is limited in total rate, and should be extended to allow for the full area of the telescope to be used, in contrast with just the central high granularity field of view (CorePix) as up to now.
- the response of the other pixels (with different shapes and sizes) should be characterized and equalized, as was done for the CorePix.
- a test mode will be implemented for regular characterization of the telescope parameters (noise, cross-talk, etc.).

Muographic analysis of the Coimbra building:

- finish the analyses on the high granularity central field view images, possibly adding information from the extension of lower granularity but higher exposure and enlarged field of view data.

- combination of muographs taken in different conditions into 3D images and quantification of the material densities will also be pursued.
- the results will be summarized in a report meant to describe the detector and analyses techniques and show the capabilities and limitations to possible uses in similar shallow settings.

Muon tomography survey of Lousal:

- the operation of the telescope is not expected to present very significant challenges, but it will allow for further testing of the autonomous RPCs, in parallel to the one at MARTA in Auger.
- the first analyses will be a direct comparison of the real data muographs with the simulated ones, aiming first at high contrast targets and then at identifying geological species.
- in a second analyses, the methods used in geophysics will be adapted to invert the muographic image and extract the density information with the corresponding uncertainties.

Communication and outreach:

- the campaign at Lousal will be accompanied by a stronger presence of the team at a science center, exploring also opportunities for more general outreach on astroparticle physics and detector R&D.
- the results from Coimbra will be used to develop outreach and education activities, but mainly to intensify contacts with other disciplines in order to identify future uses of the technique.

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.

The telescope will also be available and 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 any new telescope) is the number of electronics channels to be read out, which is now limited to 64 pixels per plane. The analyses of the response of the different shaped and sized pixels in the planes of the present telescope and their usage in imaging will thus guide the optimization of future telescopes.

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 muon telescope now delivers images almost out of the box. There is good support from several LIP groups and infrastructures, and also ICT and CCVLousal. The group is also establishing international connections for a faster learning curve in muon tomography analyses.

Weaknesses

Most team members are heavily involved with other projects and have fluctuating availability. It may be difficult to keep the present pace while looking for establishing future follow up projects.

Opportunities

The 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 Books/Chapters

- *"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

2 LIP Students Notes

- *"Muography Optimization"*, M. Inês Dias and Rodrigo Pereira , LIP-STUDENTS-21-17
- *"Muography: Simulation of Muon Telescope Sensitivity"*, Isabel Alexandre, LIP-STUDENTS-21-29

Presentations

2 Oral presentations in international conferences

- LouMu Collaboration: *" Muography for Underground Geological Surveys: ongoing application at the Lousal Mine (Portugal) "*, 2021-11-24, International Workshop on Cosmic-Ray Muography (Muography2021), Ghent, Belgium
- LouMu Collaboration: *" Muography in the university and in the museum "*, 2021-11-25, International Workshop on Cosmic-Ray Muography (Muography2021), Ghent, Belgium

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

- Pedro Teixeira: *"Tomografia de Muões na Mina do Lousal (Muões Cósmicos aplicados em Prospeção Geofísica)"*, 2021-02-11, Jornadas ICT 2021, online

5 Student presentations in advanced training events

- Pedro Teixeira: *"Muon Tomography for Underground Geological Surveys: ongoing application at the Lousal Mine (Portugal)"*, 2021-09-06, IDPASC School 2021: IDPASC School 2021, on-line
- Isabel Alexandre (supervisors : P. Teixeira, R. Sarmento, S. Andringa): *" Muography: Simulation of Muon Telescope Sensitivity"*, 2021-09-13, LIP Internship Program 2021: Final Workshop of the LIP Internship Program, Online
- Isabel Alexandre, Maria Inês Dias, Rodrigo Pereira: *"Simulação da sensibilidade do telescópio de muões e optimização da muografia"*, 2021-09-13, LIP Internship Program 2021: LIP Internship Program 2021, online
- Jorge Francisco Silva: *"Calibração de detetores RPC para muografia"*, 2021-09-13, LIP Internship Program 2021: LIP Internship Program 2021, online
- Magda Duarte: *"Muografia de um edifício"*, 2021-11-12, Prémio UMinho de Iniciação na Investigação Científica 2021, Braga, Portugal

1 Seminar(s)

- Pedro Teixeira: *"Muon Tomography Seminar – From Cosmic Rays to the Lousal Mine"*, 2021-05-18, Seminário do ICT e Mestrado em Geofísica,

2 Outreach seminars

- Pedro Teixeira: *"Muões Cósmicos na Mina"*, 2021-08-01, Ciência Viva no Verão em Rede 2021, Lousal, Portugal
- Sofia Andringa: *"LouMu e os detetores de partículas"*, 2021-08-01, Ciência Viva no Verão em Rede 2021,

Theses

2 PhD

- Pedro Teixeira: *"Tomografia de Muões com RPCs na Mina do Lousal"*, 2017-09-25 , (ongoing)
- Luís Afonso: *"Raios Cósmicos: desenvolvimento de módulos de divulgação através design participativo"*, 2021-11-23 , (ongoing)

Sources of funding

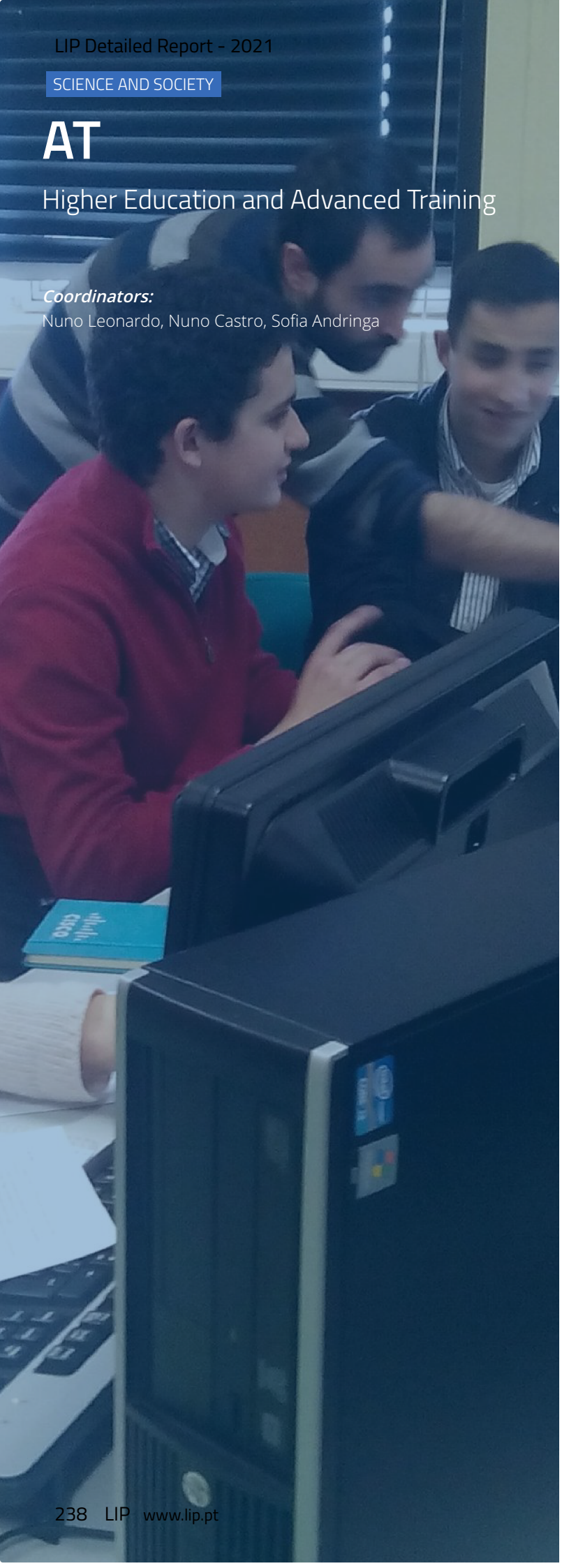
PI	Co-PI	Amount	Dates	Project / Description
Sofia Andringa	Mourad Bezzeghoud (UÉvora)	49.203 €	2021-10-15 / 2023-04-14	EXPL/FIS-OUT/1185/2021 / Muography as a new tool for geophysics

SCIENCE AND SOCIETY

AT

Higher Education and Advanced Training

Coordinators:
Nuno Leonardo, Nuno Castro, Sofia Andringa



Executive summary

The ability of the Lab to attract, engage, train and support university students in its fields of activity is paramount. LIP's Advanced Training office coordinates and facilitates the related activities.

The Laboratory permanently hosts tens of doctoral, master and bachelor students, and receives in excess of 50 internship students each year, who actively work within LIP's research groups. This enhances the close connection between LIP and associated universities, namely in Lisboa, Coimbra and Minho. The Advanced Training (AdvTrn) group implements, coordinates and promotes actions targeting university students at the several levels (undergraduate, master, doctoral), facilitating high-quality training and ensuring LIP's capability to attract, engage and retain research students.

The onset of the pandemic two years ago led to disruption of several training activities. Some of the regular actions, that were in essence built upon in-person activities, have been delayed or canceled. Others have been adapted to a remote or mixed mode of operation, and have successfully explored offline collaborating resources and novel opportunities.

The LIP Internship Program, the Lab's flagship initiative for undergraduate students, has not only resisted but even thrived. The level of dedication and participation of mentors and students has not decreased at all. Not only that but the successful integration of new means of teaching and collaborating has allowed to even increase the scope and number of participants, also overcoming some prior limitations in terms of physical resources.

Several schools and workshops were held in online format, including the 6th Lisbon Mini School on Particle and Astroparticle Physics, co-organized by LIP and CFTP, the LHC Physics Course, the 10th IDPASC School, and the Mini School on Charged Particle Therapy Applications.

FCT and LIP promoted calls within the PhD grant programmes PT-CERN and ProtoTera. In 2021, 13 such fellowships were initiated. Overall, 29 fellowships have been or are being awarded, since the start of these doctoral grant programs.

For 2022, it is anticipated, and hoped, that several activities can resume in in-person or mixed modes. Priorities include the LIP Internship Programme, Data Science school and workshop, IDPASC and LIP student workshop.

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Overview

LIP has a standing tradition of advanced training, with the Lab permanently hosting tens of doctoral, master and bachelor students, in addition to internship students, who actively work within LIP's research groups. In each of its three nodes, the Laboratory works in close connection with local universities. The capability to attract the best undergraduate and graduate students is central for LIP. The Advanced Training group exists to coordinate and promote training opportunities for university students at the several levels (undergraduate, master, PhD).

The goals include:

- to engage undergraduate students: attract university students to learn about particle physics and be part of the research carried out LIP wide, imparting the excitement of doing research in fundamental particle physics or advancing associated technologies in frontier experiments and in the context of international collaborations.

- to ensure high-quality graduate training: support baseline core training and adequate guidance of LIP's graduate students; support national and international PhD programmes and networks in LIP's fields of activity.

Assessment of the past year: objectives vs. achievements

The objectives of LIP's Advanced Training group are the consolidation and systematic enhancement of training activities and to support actions towards undergraduate and graduate students. The main goals of the group for 2021 were to hold core training activities, to the extent and in a format allowed by the persisting pandemic situation. While some of the otherwise regular events were still postponed, several of the core activities successfully took place.

LIP Internship Programme

The Lab's flagship Internship Program remains active and attractive as always. It has benefitted from the ability to systematically improve at each edition. And it has been demonstrated to be fully sustainable, even against otherwise disruptive changes such as the constraints imposed by the pandemic. In 2021, the programme had its 5th edition [1], which went with flying colors. The programme counted as always with the broad participation of LIP researchers, through the three LIP nodes, who served as project supervisors, delivered tutorials and lectures, guided topical discussions, and attended and contributed to the discussion at the final workshop. In this edition a standard large number (over 50) of project proposals were submitted. A record number of student applications (over 120) were received. The effort was made correspondingly to accept a larger number of participants (about 100, ie 82%) who were assigned a project. About 86% of the participants successfully completed the program. 70% of the projects further contributed final papers, published on the LIP website [2].

The programme kept the overall structure [3] as in previous editions: started with an introduction week in July (lectures and hands-on tutorials) [4] and ended with a two-day final workshop in September [5] in which the students presented their work. These common activities were fully held online. Lectures were complemented with thematic discussions, organized in small groups of students and researchers, held in separate virtual simultaneous rooms. In between, the participants carried out their projects, integrated in LIP's research groups. Project development was for the most part conducted through remote collaboration means, while some took place in mixed format (in-person and remote), for example, data acquisition at a lab followed by data analysis done remotely. A suite of communication and collaboration online tools was employed, following what had been tested and adopted already in the previous edition (including Zoom, Slack, Github, Colab, among others). The remote format and tools further facilitated the participation of students and co-supervisors from abroad.

The record number of participants also imposed limitations that needed to be mitigated. While the remote mode of operation eased impediments in terms e.g. of physical office/lab space or network bandwidth, the management of such a large number of computing accounts on the cluster became unfeasible. Such was addressed by introducing a so-called pre-tutorial session [6], focused on computing aspects, and by identifying projects that did not strictly require access to the cluster. Another innovation was the (re-)introduction of mid-term activities, which involved social get togethers for participants, making use of dedicated online apps. A student talk competition [7] was offered, where students prepared a short exposition of their projects in a creative manner. These were scored by fellow participants for clarity and originality, with prizes awarded to the top three contributions, announced at the final workshop [5].

Mini-school in particle and astroparticle physics: the 6th edition of the school, co-organized by LIP and CFTP, was held exceptionally in a remote format in July and gathered 25 undergraduate students from several universities [8]. It included lectures and hands-on exercises.

IDPASC school: the 10th edition of the school of the IDPASC international network, which aim is to train a new generation of high-level experts in the fields of particle physics, astrophysics and cosmology, took place online, involving 22 students [9].
Mini-school on charged particle therapy applications: consisted of a combination of student talks and invited talks by experts, in a hybrid event that included a one-say in-person workshop at LIP, involving about 40 participants [10].

Physics at the LHC course: The course took place online from March to May, in a total of 20 lectures [11]. 8 students gave a final presentation followed by discussion that served as final evaluation, valid for ECTS credits at IST.

LIP Seminars: Regularly held at the three LIP nodes; since 2020, these have taken place online [12].

Outreach for undergraduates: LIP regularly participates in events organized by physics student associations at the different universities.

Graduate programs: Two calls were open during 2021 for each of the two recently approved FCT-funded PhD grant programs, PT-CERN and ProtoTera. PT-CERN involves two domains: particle and astroparticle physics, and technologies associated with the Portuguese participation at CERN. For the former (latter) domain, 6 (3) fellowships were granted in each of the two calls. For ProtoTera, created in connection to the ProtoTera association, 5 grants were awarded in each of the two calls. LIP also coordinates the IDPASC (Particle Physics, Astrophysics and Cosmology) and DAEPHYS (Doctorate in Applied Physics and Physics Engineering) FCT-funded doctoral programs, and the IDPASC international network.

Activities for which the possibility of more direct social interaction and spontaneous discussions were considered a more fundamental element were postponed. This was the case of the LIP/IDPASC student workshop and Data Science school and symposium that shall take place in 2022.

[1] https://www.lip.pt/training/summer-student-program

[2] https://www.lip.pt/?section=training&page=student-publications

[3] https://indico.lip.pt/category/82/

[4] https://indico.lip.pt/event/932/

[5] https://indico.lip.pt/event/936/

[6] https://indico.lip.pt/event/931/

[7] https://indico.lip.pt/event/938/

[8] https://indico.lip.pt/event/928/

[9] https://indico.lip.pt/event/643/

[10] https://indico.lip.pt/event/1068/

[11] http://events.idpasc.lip.pt/LIP/events/2021_lhc_physics

[12] https://indico.lip.pt/category/70/

Lines of work and objectives for next year

While the hope is that several activities can resume in an in-person mode, it remains that detailed planning for 2022 still requires dealing with the uncertainty associated with the evolution of the pandemic situation.

Some of the key initiatives foreseen for 2022 are:

LIP Internship Programme: to ensure the next edition (6th) of the program is held successfully, retaining the participation of a large number of researchers and students across all three LIP nodes; the baseline structure and planning follow that of previous editions; it builds upon the success attained and experience acquired in the previous years to continue adopting novel features and implement further engaging actions.

Undergraduate students: the Data Science School and Workshop, focused on the link to the non-academic sector, is foreseen to be held in Coimbra in June. LIP will also continue to participate on a regular basis in events organized by the universities.

Graduate students: the joint IDPASC and LIP student workshop is foreseen for July, in Coimbra, tentatively in presencial mode. The online version of the LHC physics course will be kept. PhD grant calls are expected to open in the framework of both the PT-CERN and ProtoTera programmes.

A set of core AdvTrn activities shall be maintained and enhanced and novel actions encouraged and supported. Such improvements are based on the acquired experience, and feedback from both researchers and students (anonymous surveys amongst students are systematically conducted following core activities). Recent challenges that imposed a (temporary) transition to an online environment resulted in the experimentation of new approaches and tools, which may prove useful for further enhancing training activities also in future.

The involvement of undergraduate students especially in extended activities, such as the internship program, in addition to the core goal of their integration as effective members of research teams, allows the further acquisition of skills associated with collaboration and scientific communication.

Furthermore, the associated activities provide the opportunity also for younger LIP researchers, including MSc and PhD students, to acquire training, communication and supervision skills themselves.

The dissemination of scientific works within LIP and beyond will be pursued. This is facilitated by the recent implementation of LIP's referencing of scientific documentation. This has been spearheaded by the student internship notes [2]. It has been extended to include further contributions, such as works developed in the context of university courses coordinated by LIP members. Further extensions shall include thesis documents, as well as outreach, didactic and scientific materials produced by LIP researchers.

Medium-term (3-5 years) prospects

Advanced training shall remain a core aspect of the Lab. From facilitating scientific training to university students to engaging and supporting graduate students who fuel and advance LIP's research.

Over the last several years, through outreach and advanced training activities, the Lab has managed to attract and involve large numbers of students, who have taken part in schools, workshops and internships hosted by LIP. LIP is in this way actively contributing to the scientific training of university students. These activities, which often provide their first contact with research, facilitate a skill set both at the technical level as well as in terms of collaboration and communication. A fraction of the enrolled students systematically remains engaged in further research at LIP. This is reflected in the number of students who carry out university projects and thesis research within the LIP groups. Others pursue course work, further research, and apply the acquired skills to their academic and future professional careers. The matter of recognition of academic credit to students who take part in internships hosted by LIP shall be continually pursued with the universities.

Activities and accompanying mechanisms for reinforcing the baseline training of LIP graduate students and timely project development, assessment and conclusion shall be pursued in a more systematic fashion.

SWOT Analysis

Strengths

Recognition of the need and motivation of the team and of the entire LIP community for attracting good students to our research and to provide excellent training and guidance to those already hosted at LIP. The long experience and high reputation of LIP as a host institution and of LIP researchers as highly committed supervisors. The capability and flexibility to successfully accommodate change.

Weaknesses

Many of LIP researchers have no link, or have only a weak link, to the universities and thus no direct contact with students on a regular basis and in the classroom environment. Absence of direct funding for core AdvTrn activities.

Opportunities

The success of the activities developed in the past several years has already given a very high visibility to LIP among university students and beyond. The ambition and enhanced ability to continue to attract both national and foreign students.

Threats

The potential lack of renewed manpower to implement and steer activities in the long term. Risk that multiplication of activities could result in few poorly organized events that damage LIP's achieved reputation.

AT

Publications

34 LIP Students Notes

- *"Advanced Machine Learning Applied to Exclusive Processes"*, Manuel Peixoto, LIP-STUDENTS-21-02
- *"Assessing the class of functions learnt by Deep Learning models on low-level jet data formats"*, Irving Leander Reascos Valencia, LIP-STUDENTS-21-03
- *"High-precision timing detectors for the HL-LHC"*, Cristina Meng, LIP-STUDENTS-21-05
- *"Distinguishing Hidden Sector Particles with Machine Learning at SHiP"*, Henrique Santos, André Branco, LIP-STUDENTS-21-06
- *"Prediction of the Migdal Effect in calibrations with neutrons at LUX-ZEPLIN"*, Paulo Pires, LIP-STUDENTS-21-07
- *"Novel Jet Algorithms to Unveil the Quark-Gluon Plasma Evolution"*, Alexandre Monforte , João Fernandes , Lénea Luís, LIP-STUDENTS-21-08
- *"Development of a portable system for scintillation detection"*, Inês Dias, LIP-STUDENTS-21-09
- *"Muon efficiency performance with Tag and Probe using CMS Open Data with Z boson decaying into dimuons"*, Rodrigo Campello, LIP-STUDENTS-21-10
- *"QCD effects on the muon anomalous magnetic moment"*, André Nunes and Mário B. Amaro, LIP-STUDENTS-21-11
- *"Search for High Energy Astrophysical Multimessengers"*, João Gomes, Margarida Baptista and Miguel Godinho, LIP-STUDENTS-21-13
- *"Radiation at Mars with SRAM-based monitors"*, Alexandre Miguel Baptista Branco and Leonor de Almeida Candeias, LIP-STUDENTS-21-14
- *"Non Invasive Temperature Monitoring Device"*, Daniel Sousa and Miguel Roldão, LIP-STUDENTS-21-15
- *"Understanding Hadronization Timescales Using Jets"*, Diogo Simões and Nuno Madureira, LIP-STUDENTS-21-16
- *"Muography Optimization"*, M. Inês Dias and Rodrigo Pereira , LIP-STUDENTS-21-17
- *"Search for dark matter in association with a new Z' boson at the LHC in proton-proton collisions at 13 TeV"*, Madalena Nunes and Amélia Pinto, LIP-STUDENTS-21-18
- *"Analysis of simulated WIMP search data in the LUX-ZEPLIN (LZ) experiment"*, Diogo Severino Gorgulho , Francisco Gameiro Casalinhoand Tiago Miguel Mendes Martins, LIP-STUDENTS-21-19
- *"Development of an interface to analyze events at the Pierre Auger Observa- tory, for use in Masterclasses"*, Ricardo Correia, LIP-STUDENTS-21-20
- *"Using the HiggsML Dataset to Benchmark Machine Learning Techniques"*, Sarah Almada and Pedro Sampaio, LIP-STUDENTS-21-21
- *"Investigating flavor anomalies via B 0 → K ∗ 0 μ + μ − decay using CMS data"*, Marta Botas , Reza Jafari and Ruben Pozzi, LIP-STUDENTS-21-23
- *"Measurment of B ± meson cross section in pp collisions at the LHC"*, Henrique Legoinha, LIP-STUDENTS-21-22
- *"Hunting Forbush Decreases in the Inner Solar System with BERM"*, Anselmo Falorca and Bruno Lourenço, LIP-STUDENTS-21-24
- *"Neutron data from the SNO+ neutrino detector"*, André Soares and Teresa Miranda, LIP-STUDENTS-21-25
- *"Experimental Particle Physics with the ATLAS detector"*, Helena Lessa and Inês Serra, LIP-STUDENTS-21-26
- *"Development of a next generation detector concept to detect astrophysical gamma rays"*, Tatiana Mendes and Matilde Túbal, LIP-STUDENTS-21-27
- *"Muography: Simulation of Muon Telescope Sensitivity"*, Isabel Alexandre, LIP-STUDENTS-21-29
- *"Full acquisition and monitoring chain for a cosmic muon laboratory experi- ment: a client-server approach"*, Ana Sofia Sousa and Francisco Rodrigues, LIP-STUDENTS-21-30
- *"Anomaly detection as a test of new physics phenomena in CERN ATLAS ex-periment data"*, Edward Reeves, Rui Ferreira, Nuno Castro, Rute Pedro, LIP-STUDENTS-21-31
- *"Pierre Auger vs. The Machine: towards validation of deep-learning based reconstruction of ultra-high energy cosmic rays with new data from the Pierre Auger Observatory"*, Diogo Costa, LIP-STUDENTS-21-32
- *"Development of a new neutron detection technology"*, Gonçalo Laires Gomes, Mariana Oliveira and Inês Serra, LIP-STUDENTS-21-34
- *"Anomaly Detection as a Tool for Discovering New Physics at CERN's Large Hadron Collider"*, Miguel Caçador Peixoto, LIP-STUDENTS-21-04
- *"Deep Neural Network applications in experimental physics analysis"*, Pedro Mendeiros, Helena Santos, LIP-STUDENTS-21-33
- *"What are nucleons and pions made of?"*, Guilherme Almeida and Pedro Tomé, LIP-STUDENTS-21-35
- *"Machine Learning methods to measure the quantum numbers of the Higgs interaction to W bosons"*, J. Teixeira, R. Barrué, I. Ochoa, P. Conde Muíño, LIP-STUDENTS-21-36
- *"Simulation of large scintillators for future HEP experiments using GEANT4"*, Diogo Mendonça and Francisco Ferreira, LIP-STUDENTS-21-37

SCIENCE AND SOCIETY

ECO

Education, Communication and Outreach

Coordinator:
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5 ***Researcher(s):***
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1 ***External collaborator(s):***
Beatriz Tavares

Executive summary

The LIP Education, Communication and Outreach group (LIP-ECO) exists to boost, integrate and coordinate the laboratory's activities in the ECO domain. The group activities are divided in two interconnected and partly overlapping branches: 1) LIP's institutional communication and outreach; 2) LIP's programme for the school community - support to education and outreach.

In what concerns LIP's institutional communications, the activities developed in 2021 covered mainly the following lines of action: 1) Revision of LIP's communication Strategy, and preparatory work for this task; 2) Current management of LIP's communication channels and tools (site news, social media, reports, newsletters, public sessions, etc.) , support to LIP's groups communication needs, collaboration with CERN/EPPCN and relations with the media; 3) Continuation of the effort to towards more suitable material and human resources for the communication office to efficiently fulfill its role, namely by applying for funding and by preparing a baisc set of communication materials and resources for LIP.

As for LIP's schools programme, it was executed as normally as possible taking into account the pandemic restricition: 1) IPPOG's international masterclasses in particle physics were held online; 2) The CV Summer internships were held in person at LIP-Lisboa; 3) The CERN Teacher's schools in Portuguese Language was cancelled are replaced by an online advanced course; 4) Along the year, about 50 talks were given in schools by LIP researchers; 5) While advances and visits to the LIP-EdulLab were constrained, cloud chamber kits were used in schools for demonstration purposes.

The main public outreach events and celebrations were: UN's International Day of Women and Girls in Science, LIP's anniversary, European Researcher's Night, Participation in the FIC.a science festival, in October in Oeiras, National Day for Scientific and Technological Culture, on 24 November 2021.

ECO

Overview

ECO activities are part of LIP's societal role and essential for the recognition of its work. The LIP Education, Communication and Outreach group (LIP-ECO) exists to boost, integrate and coordinate the laboratory's activities in the ECO domain. The group activities are divided in two interconnected and partly overlapping branches:

- LIP's institutional communication and outreach
- LIP's programme for the school community - support to education and outreach

LIP's Communication Strategy Document defines the overall strategy of the team, including the priority target audiences. A detailed activity plan is prepared for each academic year, and its implementation is ensured by a core team maintaining weekly meetings. LIP-ECO involves all three LIP nodes, and they are represented in the core team.
The group's activities are developed in close collaboration with the LIP Computing Group, namely in what concerns the sharing of human resources and technical means. A close connection exists also with LIP's Administrative Services. Furthermore, these are transversal activities, which depend upon the collaboration of all the groups at LIP. For this reason, many people besides the core team contribute to LIP-ECO.
LIP has several national and international partners in communication, outreach, and support to education. At national level, 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 the IPPOG Collaboration (International Particle Physics Outreach Group), European Particle Physics Communication Network (EPPCN, which aims at fostering particle physics communication by maximising information exchange between CERN and the Member States) and the CERN forum for high-school students and teachers activities.

Assessment of the past year: objectives vs. achievements

Main 2021 communication activities

1. Management of LIP's online communication channels: public site (mainly news and events), intranet and social media. Besides Facebook, Twitter, Linkedin and Youtube, LIP is now also on Instagram. We also contributed to the maintenance of LIP's database. Due to lack of resources, it was not possible to maintain the monthly internal digital newsletter cLIP.
2. Printed communication materials: a minimal communication kit was produced for the participation in several events during Summer and Fall: set of three roll-ups introducing LIP; updated institutional flyer; new flyer with a short introduction to particle physics. LIP's reports 2020/21 were produced. The layout of the public report, which is printed and widely distributed, has been renovated. Due to difficulties with human resources, no issue of the LIP-News Bulletin was published in 2021.
3. Events: Organisation of public outreach events and celebrations (see below); support to events organised by LIP's groups: preparation of posters, banners or merchandising items; advertising among LIP's contacts, help with participant surveys.
4. In the context of EPPCN, we participated in the preparation of the ESPPU communication strategy, in a collaboration with the CERN-ECO group. In addition we translate, adapt and distribute CERN's press releases to the Portuguese media. 2021 was not a very successful year for particle physics in the media in Portugal.
5. Branding and merchandising: following the renovation of LIP's visual identity and preparation of the graphic standards manual in 2020, and although some decisions have been postponed, we proceeded with the design of a minimal set of merchandising items that may be distributed in events or to new members. Production will happen in 2022. As for the short video introducing LIP, unfurtunately we are still at the homemade version.
6. Training in science communication: several LIP PhD students collaborated regularly with the ECO group throughout the year or volunteered to participate in public events. This is both very helpful for the group and a valuable experience for students. A session on speaking in public was proposed to the participants in the LIP Internship Programme. No formal training activities for graduate students were conducted this year, mostly due to the pandemic restrictions.
7. In view of the update of LIP's communication strategy, seminars and discussion sessions were promoted with the LIP community, directorate and in science communication meetings, namely the national meeting SciCom.pt.
8. A science communication research proposal was submitted to FCT. Although this was not approved, we believe its subject will inform future projects in national or European contexts. The central topic is how to communicate the importance of fundamental science and how different approaches may contribute to this (hands-on, virtual tools, connection to art, among others).

Education and outreach for the school community

1. IPPOG's International Masterclasses in Particle Physics were organized in online mode only, but a new activity related to proton therapy methods was introduced (Proton Therapy Masterclass).

2. The regular CERN Teachers Programme in Portuguese Language was cancelled due to COVID-19 restrictions on the CERN side. An advanced online programme for a limited number of past participants in the program was held, featuring updates in particle physics and other fields.
3. Clubes Ciência Viva, for which and with whom we have organized sessions with cloud chambers and talks about cosmic rays and particle physics; LIP accepted to be the scientific partner of 11 new proposals of school science clubs, to become official Clubes Ciência Viva.
4. The Science in the Summer internship programme that hosted 12 participants at LIP Lisboa for one week full time.
5. LIP maintained its participation on the CV "Space goes to school" event, with 14 talks about space and particle physics.
6. Support to the beamline for Schools (BL4S) competition participants.
7. Talks and cloud chamber construction sessions in schools.
8. Involvement in IPPOG; since Jan. 2021 one of our members is co-chair of the Collaboration.
9. Participation in the FIC.a science festival, that involved a presence of two or three scientists during the opening hours of the festival, the LIP+CERN stand featured CERN's LHC Interactive Tunnel ("Proton Football" and "Proton Therapy planning"), and other LIP exhibits.
9. LIP-EduLab, due to pandemic restrictions, did not developed much; still it was used to develop several cloud chamber kits, that were bought by two Clubes Ciência Viva associated with LIP.

Main public outreach events and celebrations

1. UN's International Day of Women and Girls in Science: on 11 February 2021 we organised an online debate on gender issues in science, with a panel including the secretary of state for science, the president of FCT, the president of the national physics students association, a science journalist and a science teacher. Close to 100 people followed the very lively and insteresting discussion.
2. LIP's anniversary: due to the restrictions imposed by the pandemic, we celebrated the 35 years of LIP with an online session meant for members, former members and friends of LIP. The session started with a tribute to Armando Policarpo.
3. European Researcher's Night: on the last Friday of September 2021, we celebrated both online (with a talk on FCC and a virtual visit to CMS) and in-person in all the three towns where LIP has premises. Although there were still restrictions on number of people and distancing, the enthusiasm for "real" interactions was clear and much larger than expected.
4. Participation in the FIC.a science festival, in October in Oeiras.
5. National Day for Scientific and Technological Culture: On 24 November 2021, a teacher training action was conducted at LIP. During the whole week, a campaign was conducted in the social media in which LIP researchers and our followers shared their choice for several science-related themes: books, songs, 2021 events, etc.

Lines of work and objectives for next year

The discussion process towards the revision of LIP's communication strategy during 2021 (see details in section "Medium Term (3-5) Prospects") resulted in the definition of:

- A clear overall goal of building a solid and much wider reputation for LIP.
- A new set of priority audiences: internal, science community at large, and media.

Concerning internal communications, several action designed to consolidate the structure and procedures and to foster group participation are foreseen. In particular:

- LIP's intranet will be used as a dynamic internal communication hub.
- Conduct an internal communication survey throughout the year.
- Implement the new member welcome procedures and welcome kit.
- Collaborate with the Student's Council for the organisation of more appealing social events in occasions such as LIP's anniversary or the Jornadas: concerts, PubPhD-style talks, etc.
- Science communication and media training to be proposed to LIP users: how much and how will depend on the available resources and opportunities.

As for external communication, the focus will be put on partnerships with other institutions, and on fostering visibility. Concerning partnerships, the following actions are foreseen:

- Organisation of public events in collaboration with other institutions.
- Invite researchers from other institutions and areas the write for the LIP-news Bulletin.

- Similarly, broaden the span of LIP's seminar subjects.
- Participate in the SciCom.pt conference.
- Strengthen the collaboration with our partner universities' communication offices.
- Search for opportunities and partners to apply for funding.

If financial and human resources are available, we plan also to:

- Produce a short institutional video introducing LIP.
- Create a small portable exhibition on particle physics and LIP (collaboration with CERN).
- Very much increase our efforts towards the media.

Concerning activities for schools, the priorities will be the following:

- To conduct all the regular programmes as normally as possible but obviously taking into account the restrictions still imposed by the pandemic: IPPOG's Masterclasses; CERN teachers programme in presence; support to the CV Clubs; Space goes to school and other sessions in schools; support to BL4S; summer internships.
- LIP-EduLab: development of new demonstration and hands-on tools that can be shown/proposed to schools visiting LIP, or taken to schools. A group involving all three LIP nodes has been created and will work towards this goal.
- Keep the high level of participation in IPPOG.

Public events are foreseen in the following occasions:

- International day of Women and Girls in Science
- LIP's anniversary
- Higgs@10 + Start of LHC run 3
- Jornadas LIP
- European Researcher's Night
- National Week for the Promotion of Scientific and Technological Culture.

Medium-term (3-5 years) prospects

The revision of LIP's communication strategy conducted during 2021 brought forward a clear goal for the next few years: to build a solid and much wider reputation for LIP. For that our list of priority audiences must be enlarged. In the previous strategy we focused on internal communications, on our most direct partners (LIP associates and universities) and on attracting graduate students. In the revised strategy, we must bring in the science community at large and the media, while keeping internal communications in the top priority list. Specific strategies will have to be put in place for building a much wider netowrk with other R&D institutions, as well as stronger connections with the media. As for the messages, two aspects came out as being worth reinforcing in LIP's communication: the special role of LIP as the institution that represents CERN in Portugal; and all aspects concerning the social role of LIP, in particular within partnerships with other national institutions. For that, LIP communications need to be more efficient and focused. As a first step we will conduct a full revision of our communication channels (which of them need to be improved or replaced?). Also, evaluation procedures must become part of the routine. This will also require further human and material resources. In practice, it is essential to keep the existing resources for design, and to find a way to reinforce the team in what concerns content development/writing. Attempts to get our own funding will also continue.

SWOT Analysis

Strengths

Motivation of the team and wide range of expertises covered (reinforced with dedicated Design expertise in 2020); Increasing awareness of the importance of ECO at LIP; Regular participation of graduate students and young researchers in ECO activities; LIP-ECO includes all LIP nodes working together.

Weaknesses

Scarcity of dedicated human and material resources. Most team members devote only a small fraction of their time to ECO. There is a constant struggle between regular, daily talks and new/bigger projects. After dealing with every-day tasks, there is little time left for anything more.

Opportunities

ECO activities are increasingly considered essential in research institutions. LIP has a network of 1400 high-school teachers distributed all over the country. We are well integrated in international ECO networks. Recent partnerships with national research institutions, some with strong ECO groups.

Threats

We did not yet manage to build for LIP a solid reputation within the media and the national scientific community at large. Although explainable, this threatens our position. Difficulties in scientific employment and funding in Portugal severely impact on the resources available for activities such as ECO.

ECO

Publications

2 International Conference Proceedings

- *"The importance to engage: education and outreach highlights"*, Pedro Abreu for the IPPOG Collaboration, PoS(ICHEP2020)002
- *"International Particle Physics Outreach Group: Reaching across the globe with science"*, Pedro Abreu for the IPPOG Collaboration, PoS(LHCP2021)157

Presentations

About 50 Outreach seminars in schools and other settings

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

- Pedro Abreu: *"Engaging teachers for non formal education in modern physics"*, 2021-06-29, 2021 "PoLS-T Exchange: Building a Global Network of High School Physics Teachers" – Virtual Summer Conference, Harvard University, online via perusall

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

- Pedro Abreu for the IPPOG Collaboration: *"IPPOG – Reaching Across the Globe with Science"*, 2021-06-07, 9th LHC Physics Conference: LHCP2021 - 9th LHC Physics Conference, Paris, France (online via Zoom)

2 Presentations in national conferences

- C. Espírito Santo, J. Gonçalves de Sá, N. Castro, R. Ponce: *"Como comunicar ciência fundamental?"*, 2021-06-24, SciComPt 2021, online
- Catarina Espirito Santo: *"Comunicacao no LIP - para uma atualizacao da estrategia"*, 2021-06-26, SciCom Pt 2021,

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

- Ricardo Gonçalo: *"Closing Talk: the European Strategy for Particle Physics"*, 2021-11-20, Advanced CERN Portuguese Teachers School, Online

Sources of funding

PI	Co-PI	Amount	Dates	Project / Description
Catarina Espírito Santo		23.500 €	2021-01-01 / 2025-12-31	EPPCN-KE2826 -Amend / EPPCN Agreement Amendment
Pedro Abreu		100 €	2021-06-01 / 2021-09-30	ECO - OCJF 2021 / Ocupação Científica de Jovens nas Férias 2021

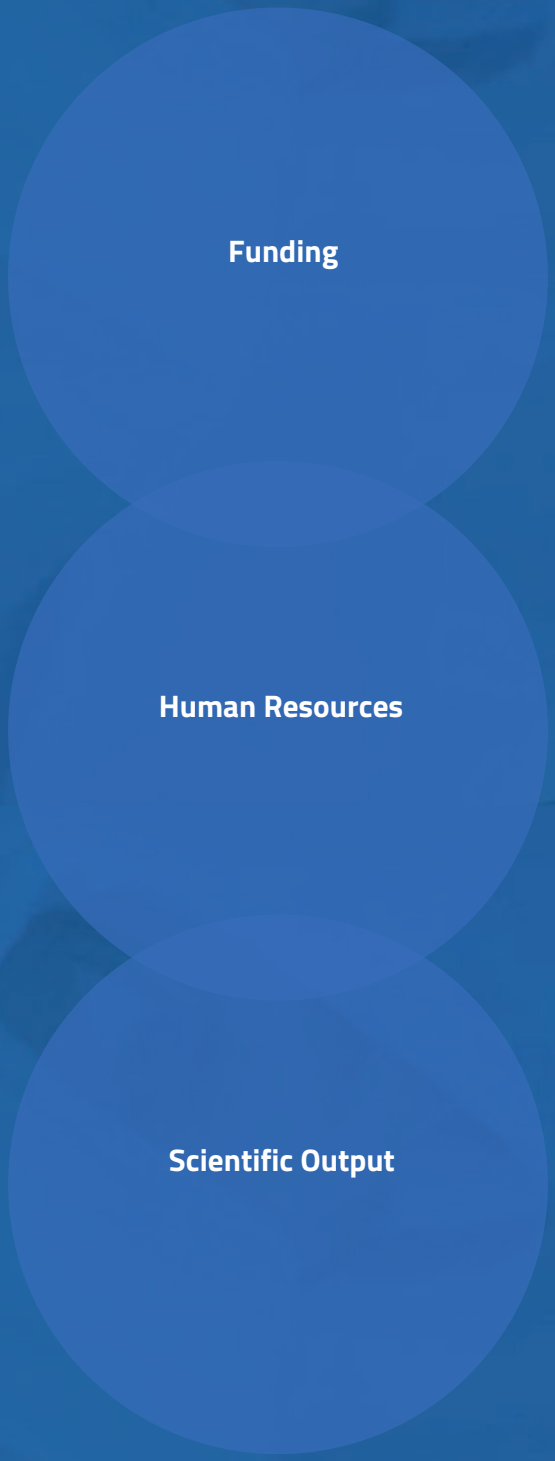
Main LIP Organized Events

- **"PANIC - Particles and Nuclei International Conference"**,
  Lisbon, Portugal (online),
  2021-09-05 / 2021-09-10
- **"12th International workshop on Multiple Partonic Interactions at the LHC"**, Lisbon, Portugal
  (hybrid online+presential)
  2021-09-11 / 2021-09-15
- **"Particle Physics for the Future of Europe"**, IST, Lisbon,
  2021-09-28 / 2021-09-28
- **"LIP Internship Program 2021"**,
  All LIP nodes,
  2021-07-01 / 2021-09-30
- **"IDPASC School 2021"**, online,
  2021-09-06 / 2021-09-16
- **"Portugal-CERN-Europa: Ciência e tecnologias nas próximas décadas"**, IST, Sacavém + Online,
  2021-07-02 / 2021-07-02

Awards to LIP Members

- **Jonathan Hollar:**
  "CMS 2021 Award", 2021-02-01
- **Luis Amorim:**
  "UMinho Award for Initiation in Scientific Research 2020", 2021-04-30
- **Joana Gonçalves-Sá:**
  "Inspiring Women" Award - Science category,
  2021-05-28
- **Marco Alves Pinto:**
  "RADECS 2020 Best Data Workshop Paper Award",
  2021-09-16
- **Magda Duarte:**
  "UMinho Award for Initiation in Scientific Research 2021",
  2021-11-12
- **Miguel Peixoto:**
  "UMinho Award for Initiation in Scientific Research 2021",
  2021-11-12

Summary Tables



FUNDING

Group	Code	Amount	Dates	LIP node
ATLAS	CERN/FIS-PAR/0033/2019	191.250 €	2019-09-01 / 2021-09-30	LCM
"	CERN/FIS-PAR/0002/2019	180.000 €	2019-09-01 / 2021-08-31	LCM
"	Fundação La Caixa - Inês Ochoa	115.500 €	2020-07-01 / 2023-06-30	LCM
"	CERN/FIS-PAR/0010/2021	165.000 €	2021-09-01 / 2023-08-31	LCM
"	CERN/FIS-PAR/0026/2021	192.672 €	2021-10-01 / 2023-09-30	LCM
CMS	CERN/FIS-INS/0032/2019	200.000 €	2019-08-01 / 2021-09-15	L
"	CERN/FIS-PAR/0025/2019	200.000 €	2019-08-01 / 2021-10-31	L
"	CERN/FIS-INS/0029/2021	200.000 €	2021-09-16 / 2023-09-15	L
"	PTDC/FIS-PAR/1214/2021	248.366 €	2022-01-01 / 2024-12-31	L
"	CERN/FIS-PAR/0005/2021	185.000 €	2021-11-01 / 2023-11-30	L
Pheno	824093 - STRONG-2020	188.500 €	2019-06-01 / 2023-11-30	LCM
"	835105 - YoctoLHC	399.062 €	2019-10-01 / 2024-09-30	LCM
"	CERN/FIS-PAR/0029/2019	45.000 €	2019-11-15 / 2021-11-14	LCM
"	CERN/FIS-PAR/0024/2019	90.000 €	2020-07-01 / 2022-06-30	LCM
"	CERN/FIS-PAR/0010/2019	20.000 €	2020-09-01 / 2022-08-31	LCM
"	CERN/FIS-PAR/0037/2021	45.000 €	2021-11-15 / 2023-11-14	LCM
"	EXPL/FIS-PAR/0905/2021	49.464 €	2021-12-01 / 2023-05-31	LCM
"	EXPL/FIS-PAR/1195/2021	49.922 €	2022-01-17 / 2023-07-16	LCM
"	CERN/FIS-PAR/0032/2021	80.000 €	2022-07-01 / 2024-06-30	LCM
FCC	aAmuse - Project 101006726	115.000 €	2022-01-01 / 2025-12-31	LCM
"	CERN/FIS-PAR/0035/2021	15.000 €	2022-04-01 / 2024-03-31	LCM
P&QCD	CERN/FIS-PAR/0022/2019	155.000 €	2019-09-01 / 2021-09-30	L
"	CERN/FIS-PAR/0016/2021	165.000 €	2021-10-01 / 2023-09-30	L
NUC-RIA	EXPL/FIS-NUC/0364/2021	49.874 €	2021-10-15 / 2023-04-14	L
"	CERN/FIS-PAR/0009/2021	20.000 €	2022-04-01 / 2024-03-31	L
NPstrong	IF/00898/2015	22.382 €	2017-04-01 / 2022-03-31	L
"	CERN/FIS-PAR/0023/2021	70.000 €	2022-03-15 / 2024-03-14	L
AMS	CERN/FIS-PAR/0013/2019	50.000 €	2019-09-01 / 2021-11-30	L
"	CERN/FIS-PAR/0007/2021	45.000 €	2021-12-01 / 2023-11-30	L
Auger	CERN/FIS-PAR/0034/2019	135.000 €	2019-09-01 / 2021-08-31	LCM
"	CERN/FIS-PAR/0031/2019	75.000 €	2019-09-01 / 2021-09-30	LCM
"	CERN/FIS-PAR/0012/2021	135.000 €	2021-09-01 / 2023-08-31	LCM
"	CERN/FIS-PAR/0020/2021	70.000 €	2021-10-01 / 2023-09-30	LCM
SWGO	PTDC/FIS-PAR/29158/2017 e POCI/01-0145-FEDER-029158	239.885 €	2018-05-15 / 2021-05-14	LC
"	PTDC/FIS-PAR/4300/2020	249.585 €	2021-05-15 / 2024-05-14	LC

Group	Code	Amount	Dates	LIP node
DarkMat	IF/00877/2015/CP1311/CT0002	50.000 €	2016-11-01 / 2022-02-28	C
"	PTDC/FIS-PAR/28567/2017	239.807 €	2018-09-01 / 2021-05-31	C
"	PTDC/FIS-PAR/2831/2020	249.948 €	2021-06-01 / 2024-05-31	C
Neutrino	IF/00248/2015/CP1311/CT0001	50.000 €	2017-01-01 / 2022-03-31	L
"	CERN/FIS-PAR/0012/2019	130.000 €	2019-09-01 / 2021-08-31	L
"	CERN/FIS-PAR/0014/2021	90.000 €	2021-09-01 / 2023-08-31	L
"	PTDC/FIS-PAR/2679/2021	231.005 €	2021-12-01 / 2024-11-30	L
SHiP	CERN/FIS-INS/0028/2021	40.000 €	2022-03-04 / 2024-03-03	LC
RPC	POCI-01-0247-FEDER-039808	161.255 €	2019-06-17 / 2022-04-16	C
"	CERN-FIS-INS-0009-2019	70.000 €	2020-07-01 / 2022-06-30	C
"	101004761 AIDAinnova	20.000 €	2021-04-01 / 2025-03-31	C
"	CERN/FIS-INS/0006/2021	70.000 €	2022-07-01 / 2024-06-30	C
nDet	CERN-FIS-INS-0009-2019	70.000 €	2020-01-01 / 2021-12-31	C
nDet	EXPL/FIS-NUC/0538/2021	49.957 €	2022-01-01 / 2023-06-30	C
GasDet	PTDC/FIS-NUC/3933/2021	62.910 €	2022-01-01 / 2024-12-31	C
LqXe	CERN/FIS-INS/0026/2019	35.000 €	2020-11-01 / 2022-10-31	C
"	CERN/FIS-INS/0013/2021	35.000 €	2022-11-01 / 2024-10-31	C
ORimag	CERN/FIS-TEC/0019/2019	90.000 €	2020-01-01 / 2021-12-31	C
"	LISBOA-01-0247-FEDER-045904	222.004 €	2020-01-01 / 2022-12-31	C
"	CERN/FIS-TEC/0017/2021	90.000 €	2022-01-01 / 2023-12-31	C
SpaceRad	ESA: 1-7560/13/NL/HB	300.000 €	2014-02-18 / 2022-03-31	L
i-Astro	871158-AHEAD 2020	30.000 €	2020-03-02 / 2024-12-01	C
"	4000136945 GLOSS	106.153 €	2021-06-01 / 2024-06-30	C
"	EXPL/FIS-PAR/0333/2021	49.966 €	2022-01-01 / 2023-06-30	C

Group	Code	Amount	Dates	LIP node
GRID	INCD 01/SAICT/2016 - nº 022153	223.000 €	2017-07-18 / 2022-07-17	L
"	EOSC-hub grant 777536	338.687 €	2018-01-01 / 2021-03-31	L
"	EOSC-synergy grant 857647	433.000 €	2019-09-01 / 2022-10-31	L
"	POCI-01-0247-FEDER-045924 LISBOA-01-0247-FEDER-045924	249.561 €	2020-03-31 / 2023-03-31	L
"	EUROCC	296.220 €	2020-09-01 / 2022-12-31	L
"	EGI-ACE	196.238 €	2021-02-01 / 2023-08-31	L
"	EOSC-Future	160.375 €	2022-01-01 / 2024-12-31	L
"	CERN/FIS-COM/0018/2021	29.999 €	2022-03-21 / 2024-03-20	L
"	interTwin	342.812 €	2022-06-01 / 2025-05-31	L
"	AI4EOSC	350.250 €	2022-06-01 / 2025-05-31	L
"	DT-GEO	542.875 €	2022-06-01 / 2025-05-31	L
"	iMagine	222.125 €	2022-06-01 / 2025-05-31	L
SPAC	FARE - Fake News and Real People (ERC)	1.499.844 €	2020-10-01 / 2025-09-30	L
LOMaC	EXPL/EME-NUC/1311/2021	49.964 €	2022-01-01 / 2023-06-30	L
SimBigDat	PTDC/FIS-PAR/29147/2017, POCI/01-0145-FEDER-029147	239.990 €	2018-07-01 / 2021-06-30	LCM
"	PTDC/FIS-MAC/2045/2021	18.750 €	2022-01-01 / 2024-12-31	LCM
"	CERN/FIS-COM/0004/2021	30.000 €	2022-02-01 / 2024-01-31	LCM
MuTom	EXPL/FIS-OUT/1185/2021	49.203 €	2021-10-15 / 2023-04-14	LCM
ECO	EPPCN-KE2826 -Amend	23.500 €	2021-01-01 / 2025-12-31	LCM
"	ECO - OCJF 2021	100 €	2021-06-01 / 2021-09-30	LCM

Human Resources on research

Group	FTE	Heads(*)	Researchers	Technicians	PhD	Master	Undergrad	Additional	External
ATLAS	28.2	44	17	6	9	12	16		8
CMS	12.3	16	9	2	3	2	12		9
Pheno	20.3	32	18	1	8	5	6		20
FCC	0.0	9	8		1				
P&QCD	4.5	7	4	1		2	5		1
HADES	0.5	4	2	2			1		
NUC-RIA	9.3	18	7	2	4	5	4		1
NPStrong	5.4	8	5		1	2	4		
AMS	3.3	5	4		1		3		1
Auger	12.4	23	13	4	3	3	12		3
SWGO	6.4	18	11	4	2	1	4		5
DarkMat	10.5	21	10	2	1	8	7		
Neutrino	6.8	12	8	1	2	1	4		
SHiP	2.1	7	4	2		1	2		
RPC	5.5	17	8	7	1	1			
nDet	0.8	4	4				3		1
GasDet	4.0	9	7		2		1		1
LqXe	0.8	3	3						
ORimag	5.6	11	7		1	3			
Dosimetry	12.6	25	6		11	8	2		
SpaceRad	2.8	8	5		1	2	4		
i-Astro	5.3	13	6	1	1	5	1		
GRID	10.7	12	3	9					4
AdvCmp	1.2	2	1			1			3
SPAC	7.7	9	5	1	1	1		1	7
RHE	3.0	7	7						2
MuTom	0.9	13	9	2	2		1		7
total	183	258	111	33	48	64	103	2	81

(*) Please note that the total of the Persons column is not the sum of the column, as one person often participates in several

Scientific output

Group	Papers w/ Direct Contribution	Papers in Referred journals	Books, Reports and Proposals	Notes	Oral Presentations Int. Conf.	Poster Presentations Int. Conf.
ATLAS	7	74	0	20	5	3
CMS	5	74	1	20	10	0
Pheno	11	11	0	2	8	0
FCC	0	0	0	0	0	0
P&QCD	1	5	0	1	2	0
HADES	0	2	0	0	0	0
NUC-RIA	5	7	0	0	1	0
NPStrong	2	2	0	0	6	0
AMS	0	5	0	0	2	0
Auger	4	9	0	5	0	0
SWGO	5	5	1	4	3	2
DarkMat	2	5	0	1	1	2
Neutrino	2	7	1	2	2	0
SHiP	0	2	1	1	0	0
RPC	2	3	0	0	0	0
nDet	2	2	0	1	1	0
GasDet	0	4	0	0	0	0
LqXe	1	2	1	0	0	0
ORimag	1	1	0	0	1	1
Dosimetry	1	1	0	0	4	3
SpaceRad	1	2	0	1	3	2
i-Astro	2	4	0	0	1	3
GRID	1	1	2	6	5	0
AdvCmp	0	0	0	0	0	0
SPAC	1	1	1	0	6	2
TagusLIP	0	0	0	0	0	0
CCMC						
SimBigDat	4	4	0	0	0	0
RHE	1	1	0	0	0	0
MuTom	0	0	1	2	2	0

Scientific output

Group	Other Presentations	Proceedings	PhD	Master	Events
ATLAS	28	3	3	5	0
CMS	27	3	0	1	0
Pheno	12	4	1	2	1
FCC	4	0	0	0	0
P&QCD	2	0	0	0	2
HADES	0	0	0	0	0
NUC-RIA	2	1	0	2	0
NPStrong	7	0	0	3	2
AMS	2	0	0	0	0
Auger	4	0	0	2	0
SWGO	4	4	0	2	0
DarkMat	2	0	1	3	0
Neutrino	16	0	0	0	0
SHiP	0	0	0	1	0
RPC	0	0	0	0	0
nDet	0	0	0	0	0
GasDet	0	0	0	0	0
LqXe	0	0	0	0	0
ORimag	7	0	0	0	0
Dosimetry	1	1	0	5	0
SpaceRad	5	0	0	0	0
i-Astro	9	1	0	1	1
GRID	8	0	0	0	0
AdvCmp	0	0	0	1	0
SPAC	20	1	0	0	0
TagusLIP	0	0	0	0	0
CCMC					
SimBigDat	4	2	2	2	0
RHE	1	2	2	0	0
MuTom	4	0	0	0	0

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA
EXPERIMENTAL DE PARTÍCULAS