LIP detailed report/plan 2020/2021

Editors:
Catarina Espírito Santo
Ricardo Gonçalo
Nuno Leonardo

Design:
Carlos Manuel

Database:
Helmut Wolters
Hugo Gomes

Table of Contents

Foreword

Mário Pimenta
President

We are living in strange times, where the future may change radically every day; times of uncertainty, times of opportunities...

LIP was able to adapt itself to the difficult and stressful work conditions of this past year; trying to help society as much as possible in the first moments when a lack of medical and sanitary equipment was a reality, with initiatives like the design and construction of low-cost, technically easy to implement, ventilator prototypes for COVID-19 emergency clinical intensive care, as well as producing face shields for health professionals in nearby hospitals; trying to keep "business almost as usual" with a massive use of tele-working and, whenever physical presence was essential and allowed, strictly complying with the recommendations and rules from the Universities and Health authorities.

We all have the feeling of an almost lost year but, in fact, the World didn´t stop. Relevant moments for our future were, for instance: the approval of the European Strategy for Particle Physics (ESPP) by the CERN Council; the evaluation by the FCT of the Associated Laboratories; the start of activity of the ProtoTera association.

The ESPP will have a central role in the future of our domain. In the short and medium-term, priority is given to the completion and exploitation of the High-Luminosity LHC, but keeping always in mind that the post-LHC era will come soon enough, which implies, already now, launching a huge scientific, technical, political and societal effort. The precision (Higgs factory) and the energy (100 TeV) frontiers are the top priorities, which may be attainable with the construction of the Future Circular Collider (FCC) at CERN. In parallel, it was strongly recommended to maintain the European support for neutrino physics, astroparticle and nuclear physics, as well as, to increasingly pay attention to societal aspects, such as training and knowledge transfer, and to the minimisation of the environmental footprint.

Portugal, LIP and the remaining Portuguese particle physics community have actively followed and participated in this two-year long process and are fully engaged in its successful realization, maintaining European leadership in science, technology and engineering and contributing to a better and peaceful world, as stated in the CERN convention, signed in the fallout of the massively destructive second World War.

A new cycle of evaluation of the Associated Laboratories in Portugal took place during 2020 and should be concluded soon. The defined priorities were: the contribution to public policies; the capability to create and sustain permanent scientific employment; increasing the degree of internationalization and the capability to attract international talent and funding. The goal of this evaluation was not to rate the scientific performance of the institutions, which had been the object of the research units evaluation, held two years before, in which LIP was classified as Excellent. The positive aspect of the evaluation process for LIP was that the jury, composed exclusively of Portuguese members, recommended that LIP should remain as an Associated Laboratory keeping the same level of funding. However, we deeply disagree with the overall appreciation of the Jury, which was basically centred on the ability to obtain external funds. External funding is undeniably an important factor, but such ability must necessarily be assessed in the context of the scientific activity developed by each Laboratory. LIP is a Laboratory whose main object is fundamental science, and whose first mission is the development of High Energy Physics in Portugal, namely ensuring Portugal's successful participation in CERN and in other large international scientific infrastructures. It is well known, although ignored by the Jury, that CERN's financing model relies essentially on the contribution of national funding agencies. This model has no parallel in other institutions with international projection, whose financing is ensured through the transfer of EU funds. Nonetheless, LIP has been in a sustained path towards reducing its dependence on direct funding from FCT, by increasing the much-desired international funding. Both our path and the new funding already secured, increasing the international funding level from 10% of the total budget to 15% already in 2021, were sadly ignored.

Globally, the number of recommended Associated Laboratories was 40, while previously only 26 had this status, whose individual funding was kept basically the same. Nobody was really satisfied with the outcome, as the general expectations were much higher. Furthermore, there is still no apparent consensus on what should be the model that ensures a medium and long-term sustainable future for the Associated Laboratories, according to their own specificities, nor there is a consensus on the corresponding creation, at appropriate levels, of the much-needed scientific employment. Universities should be part of the solution, but this is even more difficult and complex. Anyhow, we should all be acutely aware that we must continuously demonstrate the scientific, technological and societal impacts of our activities. Both to society at large

and also to the Portuguese scientific community in domains a priori further away from ours.

ProtoTera, the Portuguese Association for Proton Therapy and Advanced Technologies for Cancer Prevention and Treatment, was formally created in December 2020. The association started its activity during the Covid-19 pandemic crisis. Its first goal is the development of infrastructures for the treatment of cancer patients and for cancer research. It will use proton beams with energies of 250 MeV and 70 MeV, respectively, in Loures (in an extension of the CTN/IST campus) and in Coimbra (in the ICNAS/UC premises). The Loures unit will have 2 or 3 general purpose treatment rooms and 1 research room, while the Coimbra unit will be dedicated to the treatment of ocular melanoma and to the production of new radioisotopes for medical applications. The medical coordination and the patient screening and selection will be coordinated by the Grupo Hospitalar Instituto Português de Oncologia Francisco Gentil (GHIPOFG) which is, with IST, UC and LIP, a founder of the ProtoTera association. In parallel, ProtoTera has the mission to develop postgraduate education and training actions for medical and non-medical specialists, namely physicians, physicists, engineers and medical physicists, to build-up the required pool of skilled specialists for the treatment and research programs.

One year after, where do we stand? The requirements and technical specifications for the proton therapy unit in Loures are well advanced and practically ready to be submitted to the international advisory committee that was meanwhile constituted. In Coimbra, the best design options are under study, in collaboration with CERN, to provide intense beams and lower energy for radioisotope production, or higher energy and low intensity beams for eye treatment. The detailed implementation plan for the Loures infrastructure is being discussed with the Loures municipality and is in an almost final version. The major items of the business plan were identified, and the corresponding studies should be carried out until the end of the current year. Funding opportunities were explored but not yet secured. A PhD grant program in the areas of medicine, technology and physics, that will support the installation and operation in Portugal of cancer treatment centres using proton beam therapy, was launched in collaboration with FCT. Up to 5 grants per semester may be awarded and the program is already in its second call.

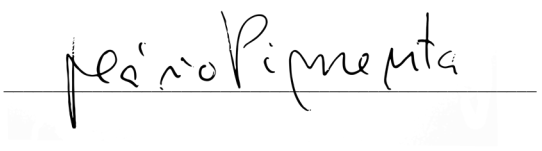
Internally, the periodic evaluation of LIP's technical and administrative staff by the LIP management finally started and its first edition is almost concluded. As a result, there was a well -deserved salary progression of many of the LIP employees. In parallel, the evaluation of LIP researchers by the LIP scientific council is reaching the conclusion of its second edition. The procedures for the recruitment of researchers for permanent positions at LIP, either by competitive and open international calls or as the result of the awarding of an ERC grant or of two FCT individual research grants, were established and clarified. As a result, five new permanent positions were awarded at LIP. These actions represent an important effort by LIP to provide better and fair working conditions to its researchers, engineers, technicians and administrative staff. However, a reasonable solution of the structural problem of scientific employment in the Portuguese scientific system will only be possible as a result of combined and coordinated efforts of the research institutions, FCT and the Universities. Finding such lasting solutions will demand, for sure, an increase in the public investment in science in years to come. But it will also require a clear effort of the scientific institutions to diversify and increase their funding sources within their own capabilities and specificities. At LIP, we set as our goal to double our external funding by the end of the period 2021-2025, as compared to our average external funding during the previous five years.

LIP education and training actions were pursued, as much as possible within the external constrains. The highlight was the start of the PT-CERN PhD grant program in particle and astroparticle physics and related scientific and technological domains. This program is in line with an already long collaboration between FCT and LIP in such programs, namely in the framework of the IDPASC PhD program network. It should also be mentioned the continuation of the LIP summer internship programme, this time necessarily adapted to the pandemic conditions, which allowed to integrate for some months in LIP's activities a significant number of students from Portuguese and international Universities.

On the coming 9th of May LIP will commemorate its 35th anniversary. We had already many cycles of life, under better or worse external circumstances, with more optimistic or pessimistic evolution scenarios in Portugal and in the World. Every day a new cycle begins, and new and greater challenges, opportunities and responsibilities are facing us. As in the past, all together, and with an increasing number of strategic national and international partnerships and an increasing connection to society, we will be able to go on fulfilling our missions.

March 2021

Mário Pimenta



RESEARCH Areas and Lines

Experimental particle and **astroparticle physics**

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

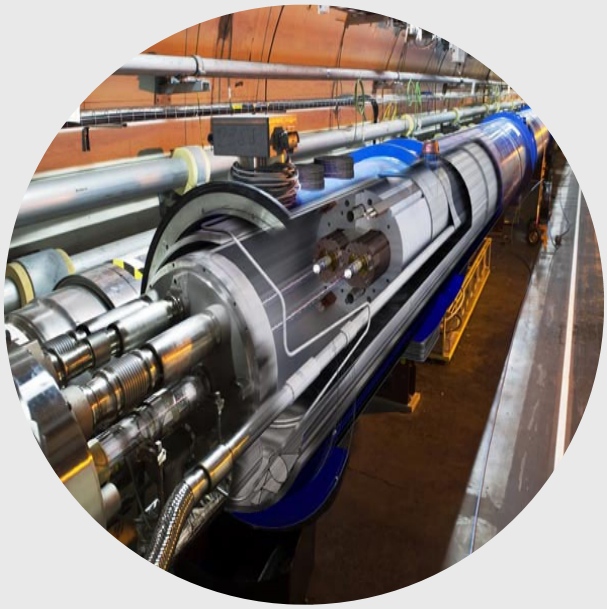
Development of **new instruments** and **methods**

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

Computing and Information Technologies

Scientific Computing

Experimental particle and astroparticle physics

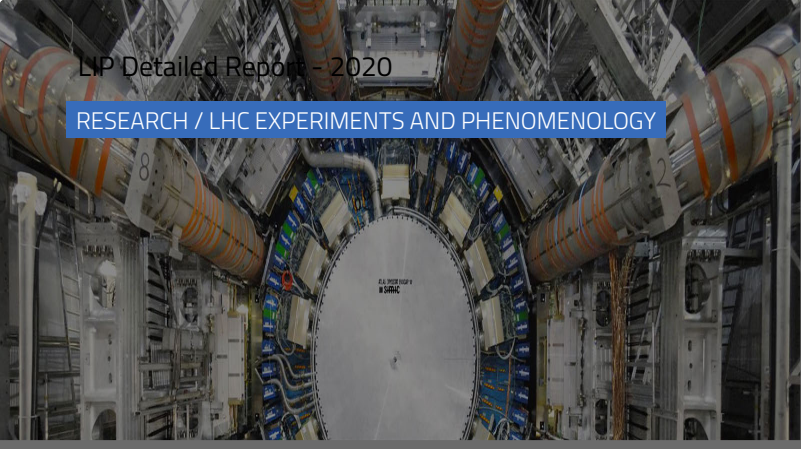


[LHC experiments and phenomenology]

ATLAS

CMS

Pheno



ATLAS

Collaboration in the ATLAS experiment at CERN

Principal Investigator:
Patricia Conde (85)

14 ***Researcher(s):***
Agostinho Gomes (85), Amélia Maio (30), António Onofre (15), António Pina (25), Filipe Veloso (80), Helena Santos (85), Helmut Wolters (60), Inês Ochoa (73), João Gentil (70), Marcin Stolarski (30), Miguel Fiolhais (30), Nuno Castro (37), Ricardo Gonçalo (75), Rute Pedro (100)

5 ***Technician(s):***
Filipe Cuim (100), Filipe Martins (100), Luís Gurriana (85), Luís Seabra (100), Rui Fernandez (100)

7 ***PhD Student(s):***
Ademar Delgado (10), Ana Carvalho (100), Ana Peixoto (100), Emanuel Gouveia (70), Ricardo Barrué (100), Susana Santos (50), Tiago Vale (100)

6 ***Master Student(s):***
Beatriz Pinheiro Pereira (83), João Ribeiro (25), Luis Coelho (66), Maura Teixeira (86), Pedro Lagarelhos (50), Ricardo Faria (50)

17 ***Trainee(s):***
Filipe Costa, Freya Haslam, Gonçalo Lage, Guilherme Calé, Inês Moreira, Jade Addison, Mafalda Nunes, Mafalda Sarmento, Miguel Lameiras, Nuno Brito, Nuno Campos, Pedro Figueiredo, Raquel Costa, Rodrigo Silva, Rudnei Machado, Tiago Martins, Vladlen Galetsky

17 ***External collaborator(s):***
André Wemans, Carolina Costa, Daniel Neacsu, Gabriela Pinhão, Gianpaolo Benincasa, Guiomar Evans, José Cordeiro, José Rufino, José Soares Augusto, Miguel Alves, Mikael Chala, Nuno Fernandes, Pedro Rato, Ricardo Pires, Rui Santos, Susana Sério, Vicente Mendes

Total FTE:
22.3

Articles in international journals:	**11** Direct contribution **4** Reviews **66** Indirect contribution
Internal notes:	**11** Collaboration notes
Students notes:	**3**
International conferences:	**3** Oral presentations **4** Posters **6** Proceedings
National conferences:	**1** Oral presentation **2** Posters
International meetings:	**12** Oral presentations **11** Posters
Collaboration meetings:	**126** Oral presentations
Advanced Training Events:	**12** Oral presentations
Seminars:	**6** Seminars **10** Outreach seminars
Completed theses:	**4** Masters

Executive summary

The Portuguese group is a founding member of the ATLAS Collaboration. Our contributions to the TileCal, the trigger system and the forward detectors are well known and acknowledged by the collaboration, as well as our expertise in hadron calorimetry and distributed computing. We are a reference in top quark physics and have exploited this expertise to lead several searches for new physics. We contributed to the Higgs boson discovery and are now measuring its properties. In addition, we have contributed to the Heavy Ion physics programme with studies of jets as probes for the Quark-Gluon Plasma (QGP).

Our members have occupied a number of coordination positions in the collaboration in most activities where the group is involved. We are currently leading the TileCal DCS and Calibration teams; the ARP (ATLAS Roman Pots) DCS system; the Physics Validation team; the Diboson, Multilepton and Extra Dimensions physics group; the Iberian Cloud; the Portuguese Federated Tier2 in the Iberian Cloud Squad; the Continuous Integration tools team of the ATLAS Physics Office and co-leading the LHC Effective Field Theory Group. Group members occupy two positions as analysis contact/editor, have contributed to three editorial boards (two as chair) of ATLAS publications, one team member was elected for the ATLAS Speakers Committee and the team leader has served as member of the ATLAS Executive Board for two years (till February 2021).

Despite the challenging pandemic situation, last year has brought important achievements in all the fields of activity of the group, with the publications of 15 articles with direct contribution from the team and five public notes, in addition to several presentations in conferences. Besides, we lead and are the main analysers of three physics studies that are now being finalised for publication. On the detector side, we honour our commitments on the DCS systems of TileCal and the forward detectors, TileCal calibration and performance studies, jets and forward physics triggers and distributed computing. On the upgrades side, we reinitiated our effort in the trigger accelerators development and advanced significantly on the development of the TileCal Phase II high voltage distribution system. Our contributions to the Hardware Track Trigger (HTT) are still ramping up due to overall COVID-19 delays.

The arrival of a new member, Inês Ochoa, with expertise and interest in the areas of Higgs Physics, Boosted Boson tagging and New Physics searches has reinforced the group activities in these areas and contributed to the development of new activities not foreseen in the working plan for this year.

Our student Ana Luísa Carvalho has received the prestigious ATLAS PhD Grant (the second for the LIP ATLAS group in recent years), improving the visibility and recognition of the group within the collaboration.

Sources of funding

PI	Code	Amount	Dates	Description
Ricardo Gonçalo	CERN/FIS-PAR/0033/2019	191.250 €	2019-09-01 / 2021-08-31	ATLAS Upgrade 2019/20
Patricia Conde	CERN/FIS-PAR/0002/2019	180.000 €	2019-09-01 / 2021-08-31	Collaboration in the ATLAS Experiment at CERN: Data Taking and Analysis
Inês Ochoa	Fundação La Caixa - Inês Ochoa	115.500 €	2020-07-01 / 2023-06-30	Bolsa Pós-doc Progama Júnior Leader “la Caixa”

Total: 486.750 €

ATLAS

Overview

The team is structured in subgroups led by senior physicists (in brackets) as described below.

Physics Analysis

- Precision Measurements (R. Gonçalo). This group resulted from joining the Top and Higgs subgroups, both of them focused on precision measurements. Our goals are to study the Yukawa couplings of the Higgs boson to the b- and t-quarks, including spin and CP properties in the coupling vertices, as well as the Vts vertex in the top sector. 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 are leading this effort in the LHC community (N. Castro, co-convenor of the LHC Effective Field Theory Working Group).
- Direct searches for new physics phenomena (N. Castro). We are searching for new exotic particles, such as vector-like quarks, additional scalars, vector bosons or gravitons, foreseen by many new physics theories. We are leading the search for flavour changing neutral currents associated to the tZq vertex; the search for monotop events, sensitive to dark matter production; and searches for new particles in final states with multiple vector and/or Higgs bosons. Our group is also contributing since the very start to the ATLAS recent effort on general searches with anomaly detection methods, and we are now leading the searches in fully hadronic topologies with boosted top quarks and large missing transverse energy.
- 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, with a current focus on 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 as well as the TileCal calibration group. We are also studying the ageing of the scintillators and WLS fibres.
- Jet Trigger (R. Gonçalo). We contribute to the jet trigger operations, monitoring and performance optimizations.
- Forward Detectors (P. Conde, N. Castro). We are leading the DCS of the ARP (ATLAS Roman Pot) detectors and 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 global ATLAS Distributed Computing operations, such as monitoring software and shift organisation.

Detector Upgrades

- TileCal Upgrade (A.Gomes, A. Maio). We are responsible for the production of the new TileCal high-voltage distribution system for Phase II, in collaboration with Portuguese industry.
- High level trigger system (P. Conde, R. Gonçalo). Our main hardware responsibility is the production of the RTM, a communications board in the Hardware Track Trigger (HTT). In addition, we contribute to HTT simulation and performance studies and to the development of real time parallel algorithms that use Graphical Processing Units (GPU) as hardware accelerators.

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)

Assessment of the past year: objectives vs. achievements

Physics studies

Precision measurements:

- Finished first measurement of the high pT cross section of the H → bb decay in VH production, published in August 2020 and the first ATLAS study of the angular variables to measure the hWW vertex spin/CP structure, using a simplified detector simulation.
- The CP-sensitive analysis of ttH with H → bb decay is expected soon; a first step of measuring ttH production with full Run 2 data, was presented at Higgs Couplings 2020 with our strong contribution.
- Finished the deployment of a new H → bb tagging algorithm, optimized for the Higgs decays, and with higher background rejection, resulting in a simulation-based note made public for BOOST2020.
- Started developing a H → bb "continuous tagger", that addresses the limitations of cutting on the neural network output by assigning a signal/background event probability.
- The study of the Vts vertex with the full 13 TeV dataset is still ongoing.

- Led and actively contributed to the effective field theory interpretation of top quark precision measurements and coordinated the recently established LHC EFT WG.

Direct searches for new physics phenomena:

- Final stage of the following full Run 2 searches for:
  - vector-like quarks in the multilepton channels.
  - flavour changing neutral currents in the tZq vertex.
- Explored the interpretation of the vector like quark searches in terms of alternative production and decay modes.
- Lead and contribute to the anomaly detection effort in ATLAS data, targeting new physics signals, using machine learning techniques. This effort is progressing in fully hadronic topologies with boosted top quarks and missing transverse energy.
- Lead and actively contribute to the search for monotop event using the full Run 2 dataset.
- Develop a topology-based approach to maximize the physics information to be obtained with the searches lead and/or participated by the LIP group for Run 3.

The following achievements were not originally planned but were possible due to a new group member:

- Finished the search for new resonances in the VH->qqbb final state using the full Run 2 data.
- Participated in the "The LHC Olympics 2020: A Community Challenge for Anomaly Detection in High Energy Physics", with results documented in a preprint review.

Heavy Ion physics:

- Contributed to heavy flavour jet production studies;
- Developed a performance study of b-jet reconstruction in pp@5 TeV collisions, under heavy ion jet algorithms, the first step towards the study of b-jet reconstruction performance in PbPb collisions.
- Concluded the performance study of b-jet triggers in PbPb collisions, that resulted in a strong contribution to a paper in preparation.
- Initiated the development of high level b-tagging algorithms, using Deep Neural Networks, that are expected to considerably improve the performance for the Run 3.

Physics Validation Coordination (I. Ochoa)

- Coordination of the Physics Validation group, liaising with the combined performance, reconstruction and simulation groups, assessing impact of planned software updates (e.g. fast simulation and multi-threading) and guaranteeing quality of physics output, critical for the ATLAS software readiness ahead of the Run 3 data-taking and Run 2 reprocessing.

Detector maintenance, operation and upgrade

Forward Detectors:

- ALFA DCS: Lab and Production DCS systems upgraded with a machine and general LS2 upgrade for OS and WinCCOA 3.16. The migration for Wiener OPC UA in Lab was concluded and ISEG is pending. Moving the OPC DA from Windows Virtual machine to OPC UA on Linux was rescheduled to 2021.
- AFP DCS: implemented a new tool to configure a new OPC UA for movement system to be used in a future technical stop. General upgrades for the cooling, movement and vacuum systems. Production system LS2 Upgrade moved to 2021.
- Re-structured the Central Exclusive Production (CEP) trigger chains to adapt to the new AthenaMT framework and Interfaces. The implementation is still ongoing. The group's human resources were reorganised to meet the ATLAS timescales for new triggers.
- The measurement of the AFP trigger efficiency with 2017/18 data was not finished (priority given to other tasks).

TileCal:

- Coordination of detector's maintenance, data quality, and milestone weeks.
- A set of six new replacement DCS computers were physically installed at the electronics cavern. The installation of the CERN Centos 8 is pending awaiting internal validation.
- The migration of the control system to a newer version of WinCC (SCADA tool) was rescheduled for the second half of 2021.
- A new DCS component for the HV Crates was designed, developed and partially tested at the test system and production system.
- Given its lower priority, the improvement of the logging of the control scripts was left for 2021.
- Coordination of Calibration: started a task force for calibration software improvement, while the preparation of the operations was given less priority due to the delay of the LHC Run 3 start.
- Evaluated the uncertainties on the PMT calibration with the laser system to improve the scintillators and WLS fibres ageing studies (see next)
- Investigated dose rate effects in the radiation damage of the scintillators and WLS fibres and developed a simplified model of light loss as a function of expected dose, to extrapolate current observations to the HL-LHC phase.
- Finished analysing the PMTs linearity with the laser system with full Run 2 data.
- The laser Run 2 paper is delayed, as the focus was put on finishing the supporting documentation: the internal notes on

laser calibration and PMT linearity in Run 2.

TileCal upgrade:

- Tested the HVRemote board prototype 2 with 48 channels. The results of the tests led to an improved design of prototype 3.
- Finished the design of the crate to house the HVRemote and HVsupplies boards. The crate is currently in production.
- Finished the design of the associated supply and control boards.
- The Cabelte cable was found to underperform in the fire propagation tests. In addition, due to Covid-19 Cabelte closed the line that was developing and producing these cables. Found another producer for cables with 16 pairs of wires within the required diameter (Tecnikabel).
- Designed the testbench for the quality control of the HV boards, that will be adapted to test the cables.
- Vertical slice test of the complete HV system was not yet possible. A partial test was done with the HVRemote board, a dedicated adaptation board and HVsupplies board.
- TMDB offline software update for Run 3 was implemented and validated. The simulation of the TMDB MC-Data overlay validation and merge tests with ATLAS software are being concluded.

The rescheduling of some DCS activities allowed the following new achievements:

1. Writing of a new component for the ELMB's firmware dedicated to the Phase II Auxiliary boards.
2. Initiated the design and development of the SCADA component for the low voltage power supplies and Auxiliary boards to be used in the Phase II.

In what concerns Jet Trigger preparations for the Run 3, both planned objectives were achieved:

- Studied the performance of the new particle flow jet reconstruction at trigger level. Problems in the track reconstruction were identified and corrected to meet the expected performance in Run 3.
- Implemented shallow copies of the jet trigger containers, reducing the jet trigger event size by nearly a factor of five.

Trigger Phase II Upgrade:

- HTT:
  - Finished the fast simulation package for the HTT tracking co-processor.
  - Contributed to the HTT performance studies, important input for the trigger architecture decisions taken by the collaboration.
  - Started the development of algorithms and services to identify and remove duplicate tracks.
  - The installation at LIP of a testing station is pending due to delays in the production of the boards in the US.
- Contributed to the new Trigger Accelerators effort:
  - Re-designed the structure of the TAC (Topo Automaton Clustering) to remove the client-server architecture.
  - Porting the code to the new framework is still ongoing due to the challenging ATLAS software environment for new students.
  - The implementation and optimization of the cluster splitting phase is being developed in collaboration with a group from Romania.

Distributed computing

- The ADC Site Status Board has been migrated to the new Grafana monitoring framework with increased functionality.
- Updating the Portuguese Tier2 operation to the changes in the ATLAS computing model for Run 3 has been started and is ongoing.

The group contributed, in addition, to the development of the Physics Office software, in particular the global DB of the ATLAS Collaboration. A new member of the group, G. Pinheiro, is a key member of the team.

Outreach and advanced training

Due to the outbreak of the COVID-19 pandemic, outreach activities were reduced with respect to our typical involvement. Nevertheless, we contributed to

- The hands-on workshops in the Lisbon Mini-school co-organised by LIP and CFTP in Costa da Caparica (February).
- Organisation, lectures and hosted 17 students in the remote LIP Internship Program in Lisbon, Coimbra and Minho. Two of these students were from secondary schools through the Ciência Viva programme "Ocupação Científica de Jovens em Férias".
- Organisation of a virtual visit to ATLAS and a public debate with PhD students during the European Researchers Night 2020 (Braga, Coimbra and Lisbon - online activity).

Lines of work and objectives for next year

Physics studies

Precision measurements:

- Contribute to the Run 2 legacy paper on the measurement of the high pT H → bb decays in VH production and prepare the ATLAS analysis of the spin/CP properties of the hWW vertex in the WH

associated production channel, that will follow.

- Finish the CP-sensitive analysis of ttH production and contribute to the ttH(H → bb) legacy paper.
- 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, and with the goal of improving b-tagging and Higgs to bb tagging capabilities at high energies.
- Finish the study of the Vts vertex with the full 13 TeV dataset.
- Lead and actively contribute to the effective field theory interpretation of different precision measurements in the top quark sector.

Direct searches for new physics phenomena:

- Finish the search for vector-like quarks in the multilepton channels using the full Run 2 data.
- Explore the interpretation of the vector like quark searches in terms of alternative production and decay modes.
- Lead and contribute to the anomaly detection effort in ATLAS data, targeting new physics signals, using machine learning techniques.
- Conclude the search for flavour changing neutral currents in the tZq vertex using the full Run 2 data.
- Lead and actively contribute to the search for monotop event using the full Run 2 dataset.
- Develop a topology based approach to maximize the physics information to be obtained with the searches lead and/or participated by the LIP group at the Run 3.
- Contribute to the combination of heavy resonance searches, with a publication planned in 2021.
- Contribute to 2D resonance search in the Y → XH channel using the full Run 2 data.
- Continue leading the subgroup dedicated to new physics searches in final states with multiple bosons and/or Higgs bosons.

Heavy Ion physics:

- Develop the b-tagging algorithm in PbPb collisions using Deep Neural Networks.
- 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: Finish the ISEG migration to OPC UA in the Lab system. Assistance for the new motherboards tests in the Lab. Production system LS2 Upgrade, including software migrations, new DCS machines and moving OPC DA from Windows Virtual machine to OPC UA on Linux.
- AFP DCS: finish the production system LS2 Upgrade, implementation of a new OPC UA for movement system and general upgrades for the cooling, movement and vacuum systems.
- CEP di-jet triggers:
  - Finish the implementation of the algorithms and trigger chain.
  - Generate MC simulated samples to study their performance.
  - Validation and performance studies to ensure readiness for data taking.

TileCal:

- Provide assistance to the detector's maintenance and report issues with the detector hardware.
- Migration of the DCS SCADA system (WinCC) to a newer version (pending from 2020).
- Improve the logging of the control scripts.
- Update of the documentation and training material for experts.
- Improve the study of the scintillators and WLS fibres ageing exploring data at a sub-cell level, to constrain the model of light loss as a function of expected dose, and increase the precision on the extrapolation of current results to the HL-LHC phase.
- Coordination of Calibration: prepare calibration procedures, software and operations for the next LHC Run 3, expected to start in early 2022.
- Conclude the approval process of the internal notes of laser calibration activities in Run 2 and on the PMT linearity as support for the laser Run 2 paper and TileCal Run 2 operations paper.
- Lead an editorial team to write the laser Run 2 paper.

In what concerns the TileCal upgrade:

- Produce final prototypes of HVremote boards, HVbus board, cables and HV supplies crate and associated boards.
- Perform a vertical slice test of the complete HV system, followed by Production Readiness Reviews of the HV packages.
- Produce testbenches for the quality control of the HV boards and cables.

- Successfully complete internal and collaboration reviews of the TileCal HV upgrade project
- Complete tests of the control of the high voltage crates and integrate it with the current HV system.
- Testing of the modified Phase II ELMB firmware, in combination with the new Auxiliary boards. Continue with the design and development of the SCADA component for the Phase II low voltage system.
- Support for TMDB offline software updates needed for L1 simulation and Run 3 offline updates.

Jet Trigger preparations for Run 3:

- Study new calibrations for the particle flow jets and the performance of the Jet Vertex Tagger (JVT), that associates jets to primary vertices.
- Contribute to the monitoring/validation shifts to ensure high quality of the jet trigger in preparation for data taking.

Trigger Phase II Upgrade:

- Contribute to the HTT effort:
  - Finish the development of software to identify and remove duplicate tracks and study its performance.
  - Install at LIP a testing station for HTT electronics boards, to allow our contribution to the firmware and to prototype and debug this system.
  - Prepare future production of the communications board for HTT.
- Continue the development of the GPU-accelerated calorimeter reconstruction:
  - Finish the implementation of the TAC algorithm in AthenaMT.
  - Performance and optimization studies with the new architecture/framework.

Distributed computing

Prepare ADC operations for the challenges of the upcoming data taking for Run 3:

- Extend the ADC Site Status Board with more monitoring information.
- Improve tools and organization of the Computing Run Coordination.
- Continue updating the Portuguese Tier2 operation to the changes in the ATLAS computing model.

Outreach and advanced training

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

Medium-term (3-5 years) prospects

The team strategic plans take into account the schedule of the LHC and the main remaining unanswered questions in Particle Physics.

In proton-proton collision physics, the focus is 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 top quark and Higgs properties are fundamental to probe the limits of validity of the SM model. The strategy is complemented with direct searches for new exotic particles, such as vector-like quarks, additional scalars, vector bosons or gravitons, foreseen by many new physics theories. 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 machine learning methods.

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

The group will continue its commitments in detector maintenance, operation and upgrades in the TileCal, the jet trigger system and the forward detectors. Regarding TileCal Upgrade, the main effort will be the full production of the new high voltage distribution system for the Phase II and the continuous upgrades of the detector control system. Systematic studies of the ageing of optical components (scintillators and fibres) and its impact on the expected performance 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. This effort will be complemented with contributions to HTT development, including simulation and performance studies, and contributions to the prototyping and the production of a communication board for the HTT. We will use our expertise in DCS to contribute to the development of the HTT control system.

SWOT Analysis

Strengths

The group accumulates know-how in the domains of calorimetry, DCS, software triggers and physics analyses. We count on experimental labs in Lisbon (LOMaC), dedicated to instrumentation in calorimetry, to the preparation, quality control and characterization of optical fibres, plastic scintillators and photodetectors. There is also expertise in electronics and advanced computing.

Our long expertise in top quark physics has placed us in a leading role in many studies of top quark properties and searches for exotic new physics phenomena. We have expertise in Higgs and Heavy Ions physics.

The arrival of a new member with competence and interest in the areas of Higgs physics, boosted boson tagging and New Physics searches has reinforced the group.

The outreach and dissemination strategy adopted since some years lead to an increased visibility of the group, with new Master and PhD students joining last year.

Weaknesses

Reduced number of postdocs and early career researchers, reflecting a national problem in scientific employment, which limits the possibility for expanding the impact of the group.

The number of new Master and PhD students in some of the LIP nodes continues to be small, despite the positive evolution. The effort to attract new students to all the activity areas should continue.

Opportunities

We are a nation-wide team with connections to many of the universities in the Country. The fact that three members of the group are professors at universities in Lisbon, Coimbra and Minho, places us in an optimal situation to strengthen our relation with the universities and attract new students.

The Portugal-CERN PhD grants program, together with the challenges of the LHC upgrade and the physics opportunities of Run 2, have shown to provide excellent opportunities for funding high-level students in all areas, including technical research topics.

The growth of the Phenomenology and Data Science fields at LIP provides an excellent opportunity for synergies, namely in the context of HL-LHC

Threats

The human power situation continues to be delicate, in particular in what concerns technicians and postdocs. The instability and level of the funding does not allow ensuring medium term support in this area. The situation may become critical if key persons leave the group.

ATLAS

Publications

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

- *"Use of a Generalised Energy Mover's Distance in the Search for Rare Phenomena at Colliders"*, M. C. Romão N. F. Castro R. Pedro T. Vale, Eur. Phys. J. C.
- *"Measurement of the azimuthal anisotropy of charged-particle production in Xe plus Xe collisions at root S-NN=5.44 TeV with the ATLAS detector"*, ATLAS Collaboration (2892 authors), Phys. Rev. C 101 (2020) 024906
- *"Transferability of Deep Learning Models in Searches for New Physics at Colliders"*, M. Crispim Romao, N. F. Castro, R. Pedro, T. Vale, Phys. Rev. D 101 (2020) 035042
- *"Study of interference effects in the search for flavour-changing neutral current interactions involving the top quark and a photon or a Z boson at the LHC"*, Maura Barros, Nuno Filipe Castro, Johannes Erdmann, Gregor Gebner, Kevin Kroninger, Salvatore La Cagnina, Ana Peixoto, Eur. Phys. J. Plus 135 (2020) 339
- *"ATLAS data quality operations and performance for 2015-2018 data-taking"*, ATLAS Collaboration (2929 authors), J. Instrum. 15 (2020) P04003
- *"Measurement of the Lund Jet Plane Using Charged Particles in 13 TeV Proton-Proton Collisions with the ATLAS Detector"*, ATLAS Collaboration (2931 authors), Phys. Rev. Lett. 124 (2020) 222002
- *"Novel Interpretation Strategy for Searches of Singly Produced Vector-like Quarks at the LHC "*, Avik Roy, Nikiforos Nikiforou, Nuno Castro, Timothy Andeen, Phys. Rev. D 101 (2020) 115027
- *"Combination of the W boson polarization measurements in top quark decays using ATLAS and CMS data at 8 TeV"*, ATLAS Collaboration / CMS Collaboration (5203 authors), J. High Energy Phys. 8 (2020) 051
- *"Performance of the ATLAS muon triggers in Run 2"*, ATLAS Collaboration (2941 authors), J. Instrum. 15 (2020) P09015
- *"Search for resonances decaying into a weak vector boson and a Higgs boson in the fully hadronic final state produced in proton - proton collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration (2897 authors), Phys. Rev. D 102 (2020) 112008
- *"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

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

- *"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, arXiv:2011.05639. Accepted at Eur. Phys. J. C.
- *"Reconstruction and identification of boosted di-tau systems in a search for Higgs boson pairs using 13 TeV proton-proton collision data in ATLAS"*, ATLAS Collaboration (2927 authors), J. High Energy Phys. 11 (2020) 163
- *"Measurement of hadronic event shapes in multijet final states at sqrt{s} = 13 TeV with the ATLAS detector"*, ATLAS Collaboration, JHEP 01 (2021) 188
- *"Search for Heavy Resonances Decaying into a Photon and a Hadronically Decaying Higgs Boson in pp Collisions at root s=13 TeV with the ATLAS Detector"*, ATLAS Collaboration (2897 authors), Phys. Rev. Lett. 125 (2020) 251802

6 International Conference Proceedings

- *"Upgrade of the ATLAS Tile Calorimeter High Voltage System"*, Agostinho Gomes, Jose Augusto, Filipe Cuim, Guiomar Evans, Rui Fernandez, Luis Gurriana, Filipe Martins, ATL-TILECAL-PROC-2019-008, PoS 370-062
- *"ATLAS Public Engagement: The CERN Open Days Experience"*, Ana Peixoto et al., ATL-OREACH-PROC-2020-004
- *"Jet Production in Heavy Ion Collisions with the ATLAS Experiment"*, Helena Santos, PoS 2020, vol. 364, p. 286
- *"Evaluation of a new visualization and analytics solution for slow control data for large scale experiments"*, Laura Sargsyan and Filipe Martins, EPJ Web of Conferences 245, 07001 (2020)
- *"Radiation hardness of the atlas tile calorimeter optical components"*, B. Pereira on behalf of the ATLAS Collaboration, J. Phys.: Conf. Ser. 1690 012053
- *"Operation and Performance of the ATLAS Tile Calorimeter"*, R. Pedro, J. Phys.: Conf. Ser. 1690 012045

5 Internal notes

- *"Study of the difference between substructure variables of large-R jets using AFII and FS simulations"*, L. F. Coelho, N. A. Asbah, J. Jovicevic, CERN-STUDENTS-Note-2020-023
- *"Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a pair of b-quarks using large-R jets"*, R. Barrué, P. Conde Muíño, R. Pedro, et al., ATL-COM-PHYS-2019-1125
- *"Regional tracking (L1Track) performance studies for HL-LHC"*, A. L. Carvalho, F. Pastore, et al., ATL-COM-DAQ-2020-043
- *"ATLAS Tile Calorimeter calibration with the Laser system during LHC Run 2"*, P. Klimek, R. Pedro, A. Ahmad, B. Pereira, H. Wilkens, A. Cortes-Gonzalez, D. Boumediene, G. Di Gregorio, ATL-COM-TILECAL-2020-029
- *"Search for CP-odd ttH production in the H->bb decay channel using 139 /fb of pp collision data at sqrt{s}=13 TeV"*, L.Carvalho, R. Gonçalo, E. Gouveia, A. Onofre, et. al, ATLAS-COM-CONF-2020-073

6 Collaboration notes with internal referee

- *"Measurement of the sensitivity of two particle correlations in pp collisions at 13TeV to presence of jets with the ATLAS detector"*, ATLAS Collaboration (H. Santos et al), ATLAS-CONF-2020-018
- *"Identification of Boosted Higgs Bosons Decaying Into bb¯ With Neural Networks and Variable Radius Subjets in ATLAS"*, ATLAS Collaboration, ATLAS, ATL-PHYS-PUB-2020-019
- *"Measurement of the associated production of a Higgs boson decaying into b b -quarks with a vector boson at high transverse momentum in pp p p collisions at s√=13 s = 13 TeV with the ATLAS detector"*, ATLAS Collaboration (R. Barrué, P. Conde Muino, R. Pedro et al.), arXiv:2008.02508
- *"Top Quarks + X Summary Plots Summer 2020"*, Geoffrey Gilles and Johannes Erdmann and (Fakultaet Physik and Baptiste Ravina and Peter Johannes Falke and Filipe Veloso, ATL-COM-PHYS-2020-591
- *"Top Quarks + X Summary Plots Summer 2020"*, The ATLAS collaboration, ATL-PHYS-PUB-2020-022
- *"Measurement of the Higgs boson decaying to b-quarks produced in association with a top-quark pair in pp collisions at sqrt{s}=13 TeV with the ATLAS detector"*, ATLAS Collaboration, ATLAS-CONF-2020-058

Presentations

3 Oral presentations in international conferences

- Ana Peixoto: *"Getting the public closer to the experimental facilities: How Virtual Reality helps HEP experiments engage public interest"*, 2020-07-28, 40th International Conference on High Energy Physics, Prague, Czech Republic (online)
- Helena Santos: *"Jet Measurements in Heavy Ion Collisions with the ATLAS Experiment"*, 2020-07-28, 40th International Conference on High Energy Physics (ICHEP) 2020, Prague - Czech Republic (online)
- Rute Pedro: *"Operation and Performance of the ATLAS Tile Calorimeter"*, 2020-10-07, ICPPA 2020, Virtual World - Moscow

4 Poster presentations in international conferences

- Ana Peixoto: *"ATLAS public engagement: The CERN Open Days experience"*, 2020-05-28, Large Hadron Collider Physics Conference (LHCP 2020), Online
- Ana Carvalho: *"The ATLAS Hardware Track Trigger performance studies for the HL-LHC"*, 2020-06-04, 8th Conference of Large Hadron Collider Physics, Online, 25 - 30 May 2020
- Ana Peixoto: *"Novel flavour-changing neutral currents in the top quark sector"*, 2020-09-11, Poster session at the TOP2020 international conference, Online
- Beatriz Pinheiro Pereira: *Radiation hardness of the atlas tile calorimeter optical components"*, 2020-10-05, ICPPA 2020, Virtual World - Moscow

12 Oral presentations in national or international meetings

- Ana Peixoto: *"Search for FCNC interactions at the LHC"*, 2020-01-31, CFTC-UL, UA and LIP meeting - Experiment vs. theory, Braga (Portugal)
- Rute Pedro: *"TileCal Operations, Calibration, Performance and Upgrades"*, 2020-02-15, Jornadas do LIP, Braga, Universidade do Minho
- Emanuel Gouveia: *"ATLAS: Higgs and Heavy Ion Physics"*, 2020-02-15, LIP Jornadas, Braga, Universidade do Minho
- João Gentil: *"Status of LOMAC/LIP infrastructure"*, 2020-02-15, Jornadas LIP, Universidade do Minho-Braga
- Agostinho Gomes: *"ATLAS: High Voltage Distribution System for the TileCal Ugrade"*, 2020-02-15, Jornadas do LIP, Braga
- Patricia Conde: *"ATLAS: Introduction to LIP-ATLAS activities"*, 2020-02-15, Jornadas do LIP, Braga
- Rute Pedro: *"Full Event Distances"*, 2020-05-18, Anomaly Detection Forum, CERN
- Rute Pedro: *"Methods for Anomaly Detection in Collider Searches"*, 2020-06-15, Anomaly Detection Forum, CERN
- Ricardo Gonçalo: *"Particle Physics for the Future of Europe - Welcome"*, 2020-07-13, Particles for Europe, Remote
- Rute Pedro: *"Deep Learning as a tool for Generic searches at Colliders"*, 2020-07-16, Mini-Workshop Anomaly Detection LHC Olympics, Virtual World - Berlim
- Tiago Vale: *"ATLAS: Top precision measurements and searches for exotic particles at ATLAS"*, 2020-09-15, LIP Jornadas, Braga, Universidade do Minho
- Nuno Castro: *"Global EFT efforts: fits and related systematics"*, 2020-10-20, 1st General Meeting of the LHC EFT Working Group, virtual world

11 Poster presentations in national or international meetings

- Luís Seabra: *"DCS of ATLAS Roman Pots Upgrade for Run 3"*, 2020-02-14, LIP Jornadas, Braga, Universidade do Minho
- Susana Santos: *"Determination of the Higgs CP properties in hadron colliders"*, 2020-02-14, LIP Jornadas, Braga, Universidade do Minho
- Emanuel Gouveia: *"Probing the CP nature of the Higgs coupling to top quarks with the ATLAS experiment"*, 2020-02-14, LIP Jornadas, Braga, Universidade do Minho
- Ana Peixoto: *"Search for Flavour Changing Neutral Currents interactions in the tZq vertex with the ATLAS Experiment at 13 TeV"*, 2020-02-14, LIP Jornadas, Braga, Universidade do Minho
- Tiago Vale: *"Search for vector-like quarks with the ATLAS Experiment"*, 2020-02-14, LIP Jornadas, Braga, Universidade do Minho
- Ricardo Barrué: *"Sensitivity to anomalous HWW couplings at ATLAS"*, 2020-02-14, LIP Jornadas, Braga, Universidade do Minho
- Ana Peixoto: *"Search for Flavour Changing Neutral Currents interactions in the tZq vertex with the ATLAS Experiment at 13 TeV"*, 2020-02-14, Poster session at the LIP Jornadas, Braga (Portugal)
- Rute Pedro: *"Machine Learning in the Search for New Physics Phenomena at the LHC"*, 2020-02-15, Jornadas do LIP, Braga, Universidade do Minho
- Ricardo Barrué: *"Sensitivity to HWW anomalous couplings at ATLAS"*, 2020-02-15, Jornadas do LIP
- Luis Coelho: *"Search for CP-odd ttH production in the H->bb decay channel with ATLAS"*, 2020-06-25, 6th IDPASC PhD students workshop, online
- Luis Coelho: *"Search for CP-odd ttH production in the H -> bb decay channel"*, 2020-06-25, 6th IDPASC/LIP PhD StudentsWorkshop, Portugal

1 Presentation(s) in national conference(s)

- Rute Pedro: *"Machine Learning na Física de Altas Energias"*, 2020-09-03, Física 2020 22ª Conferência Nacional de Física, Sessão Paralela "Astronomia, Astrofísica e Física de Partículas, Lisboa

2 Poster presentations in national conferences

- Carolina Costa: *"Sensitivity of the ATLAS experiment to anomalous interactions between the Higgs and W bosons"*, 2020-09-04, Conferencia Nacional de Física (Física 2020),
- Pedro Figueiredo: *" Investigando as interações entre o bosão de Higgs e o W com ATLAS Open Data"*, 2020-09-06, Conferência Nacional de Física (Física 2020), Lisboa

12 Oral presentations in advanced training events

- Ricardo Gonçalo: *"LHC - Past highlights and the next decade"*, 2020-02-05, Fifth Lisbon mini-school on Particle and Astroparticle Physics, Hotel Tryp Lisboa Caparica Mar - Costa da Caparica
- Rute Pedro: *"Hands-On Higgs"*, 2020-02-06, 5th Lisbon Mini-School on Particle and AstroParticle Physics, Costa da Caparica
- Ricardo Gonçalo: *"Introduction to Higgs Physics at the LHC"*, 2020-04-01, IDPASC Course on Physics at the LHC, Remote
- Patricia Conde: *"The Higgs boson Decays to b- quarks and more..."*, 2020-04-08, Course on Physics at the LHC, LIP

- Ana Peixoto: *"Search for new interactions on the top quark sector"*, 2020-06-25, 6th IDPASC PhD students workshop, Online
- Ana Carvalho: *"Search for CP-odd ttH production in the H->bb decay channel with ATLAS"*, 2020-06-25, 6th IDPASC PhD students workshop, Online
- Emanuel Gouveia: *"Probing the CP nature of the top-Higgs coupling in ATLAS"*, 2020-06-25, 6th IDPASC PhD students workshopth IDPASC PhD students workshop, online
- Tiago Vale: *"Search for vector-like quarks with the ATLAS Experiment"*, 2020-06-25, 6th IDPASC PhD students workshop, online
- Ricardo Gonçalo: *"Opening and Welcome"*, 2020-06-25, 6th LIP/IDPASC Students workshop, Remote
- Ana Peixoto: *"Search for new interactions on the top quark sector"*, 2020-06-25, 6th IDPASC/LIP PhD Students Workshop, Online
- Ricardo Barrué: *"Study of the Spin/CP properties of the Higgs coupling to W bosons with ATLAS at the LHC"*, 2020-06-2506-25, 6th IDPASC PhD students workshop, online
- Nuno Castro: *"Probing the Standard Model and Beyond at the LHC"*, 2020-07-14, Estágios de Verão do LIP

6 Seminars

- Patricia Conde: *"Probing the SM (and beyond) with Forward Proton Tagging at ATLAS"*, 2020-03-12, LIP Seminar, LIP-Lisbon
- Patricia Conde: *"Probing the SM (and more) with Forward Proton Tagging @ ATLAS"*, 2020-04-30, LIP Seminar, Online
- Helena Santos: *"Heavy Ions from the ATLAS Experiment, Seminário no LIP Coimbra - Novembro 2020"*, 2020-11-11, Café com Física, LIP Coimbra
- Inês Ochoa: *"Hunting for new physics with dibosons at the LHC"*, 2020-11-12, Seminários LIP, Online
- Rute Pedro: *"Machine Learning in Particle Physics"*, 2020-11-18, Centre for Theoretical Particle Physics - IST - University of Lisbon, Virtual World - Lisboa
- Rute Pedro: *"Machine Learning in Collider Physics"*, 2020-12-10, Seminar Lecture - University of Coimbra, Virtual World - Coimbra

10 Outreach seminars

- Nuno Castro: *"O Universo e a Físicade Partículas"*, 2020-01-29, Seminário na Escola Secundária Filipa de Vilhena, Porto
- Rute Pedro: *"Palestra "À Caça das Partículas"*, 2020-03-03, CERN International Masterclasses, IPB Bragança
- Rute Pedro: *"Palestra "À Caça das Partículas"*, 2020-03-04, CERN International Masterclasses, UTAD Vila Real
- Ana Peixoto: *"Como vemos as partículas? Actividade experimental: o bosão Z (e o Higgs)"*, 2020-03-06, International Masterclasses on Particle Physics, Braga (Portugal)
- Nuno Castro: *"O Universo e a Física de Partículas - actividade experimental: o bosão Z (e o Higgs)"*, 2020-03-06, International Masterclasses on Particle Physics, Braga
- Ricardo Gonçalo: *"LIP vs COVID"*, 2020-05-07, International Particle Physics Outreach Group (IPPOG) Collaboration Meeting, Remote
- Ricardo Barrué: *"Bosão de Higgs: uma janela para o desconhecida"*, 2020-05-21, https://www.youtube.com /watch?v=LSVwibOst74
- Inês Ochoa: *"Os desafios da Física de Partículas"*, 2020-07-02, Portugal-CERN-Europa : Ciência e tecnologias nas próximas décadas, Lisboa
- Rute Pedro: *"Tutorial LHC Open Data"*, 2020-07-15, LIP Internship 2020, Virtual World - Lisboa
- Ricardo Barrué: *"90 Segundos de Ciência"*, 2020-09-14, https://www.90segundosdeciencia.pt /episodes/ep-916-ricardo-barrue/

Theses

6 PhD

- Susana Santos: *"Study of the ttH production and Higgs couplings to Top quarks in the ATLAS experiment"*, 2010-10-30 , (ongoing)
- Ana Peixoto: *"Search for FCNC in tZ trilepton events at the ATLAS experiment"*, 2016-09-13 , (ongoing)
- Tiago Vale: *"Search for vector-like quarks in Zt/b+X events at ATLAS"*, 2016-09-13 , (ongoing)
- Emanuel Gouveia: *"Probing the CP nature of the Higgs couplings to top quarks at the Run 2 of the LHC"*, 2016-11-21 , (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)

11 Master

- Ricardo Barrué: *"Study of the ATLAS sensibility to anomalous Spin/CP components in the HWW vertex"*, 2017-01-01 / 2020-04-07, (finished)
- Maura Teixeira: *"Search for Dark Matter in Monotop Events at the Large Hadron Collider"*, 2018-10-01 / 2020-11-19, (finished)
- Luis Coelho: *"Study of the CP nature of the top-Higgs coupling in ttH events at the LHC "*, 2019-10-09 / 2020-11-26, (finished)
- 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)
- 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)
- João Ribeiro: *"Fast tracking co-processor for the ATLAS experiment upgrade for the High Luminosity phase of the LHC"*, 2016-09-01 , (ongoing)
- Nuno Fernandes: *"Development of GPU-accelerated trigger algorithms for the ATLAS experiment at the LHC"*, 2020-11-17, (ongoing)
- Pedro Rato: *"Test system for the remote high voltage distribution system of the tilecal "*, 2018-09-01 , (ongoing)
- Catarina Pereira: *"Performance of the TileCal High Voltage Upgrade System"*, 2019-09-16 , (ongoing)
- Rui Marques: *"Functional tests and calibration of the Tilecal HV prototypes"*, 2016-09-12 , (ongoing)

CMS

Collaboration in the CMS experiment at CERN

Principal Investigator:
Michele Gallinaro (100)

9 ***Researcher(s):***
Alessio Boletti (52), Jonathan Hollar (100), João Seixas (35), João Varela (100), Ksenia Shchelina (75), Nuno Leonardo (80), Pedrame Bargassa (100), Pietro Faccioli (25), Tahereh Niknejad (100)

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

5 ***PhD Student(s):***
Diogo de Bastos (100), Giles Strong (100), Mariana Araújo (50), Matteo Pisano (47), Oleksii Toldaiev (100)

1 ***Master Student(s):***
Maria Faria (50)

10 ***Trainee(s):***
Allan Jales, Armando Gonçalves, Artur Semião, Hilberto Silva, João Rocha, Manuel Leite, Rafael Pastor, Thomas Gaehtgens, Timothée Cabos, Timothée Hessel

9 ***External collaborator(s):***
Beatriz Ribeiro Lopes, Carlos Leong, Eliza Costa, Luis Ferramacho, Matteo Magherini, Miguel Silveira, Pedro Ferreira da Silva, Ricardo Bugalho, Sandro Fonseca

Total FTE:
13.7

Articles in international journals:
12 Direct contribution
80 ndirect contribution
12 Reviews
Internal notes:
11 Collaboration notes
Students notes:
6
Proposals:
1
International conferences:
5 Oral presentations
8 Proceedings
National conferences:
1 Oral presentation
1 Poster
International meetin s:
13 Oral presentations
2 Posters
Collaboration meetin s:
67 Oral presentations
Advanced Trainin Events:
25 Oral presentations
Seminars:
3 Seminars
Completed theses:
2 PhDs

Executive summary

LIP is member of the Compact Muon Solenoid (CMS) Collaboration at the LHC since its creation in 1992. The research at the LHC is central to the quest for the fundamental physics laws of Nature. 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 CMS Trigger System that performs the online selection of the interesting collisions. After the LHC start-up in 2010 LIP made major contributions to the CMS physics program, in particular to: the discovery of a Higgs boson; measurements of the top quark properties; first observation of the rare $B_s \rightarrow \mu\mu$ decays; measurement of χ and ψ and Y polarizations and cross sections; searches for a charged Higgs and a top squark. A group member served as Deputy Spokesperson of the Collaboration in 2012-13. The group is actively involved and contributing to physics analyses in the areas of top quark, Higgs boson, B mesons, SUSY, quarkonia, heavy ions, and physics with the Precision Proton Spectrometer.

The group contributed to the Phase-I Upgrade of the experiment by building and installing new High-Speed Optical Links (oSLB-oRM) that interface the ECAL electronics to the trigger system. The CMS experiment took data in Run 2 (2015-2018) at an energy of 13 TeV, and 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 Precision Proton Spectrometer (PPS) and the ECAL detectors. The LIP group continues leading the new forward PPS that took data integrated in CMS in 2015-18. 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 group participates in the construction of a new Timing Detector and in the upgrade of the barrel and endcap Calorimeters. The group is responsible for the design and construction of the readout system of the Barrel Timing Layer (BTL), including a high-performance TOF ASIC for time measurements. 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 by supplying a high-current low voltage regulator (LVR) resistant to radiation for the High-Granularity Calorimeter (HGCAL) frontend system.

It is worth noting that, in the 2019 evaluation by FCT, in which LIP was rated "Excellent", the contribution of the CMS group was explicitly recognized. Quoting the review panel report, “The CMS group, while small in size, is really outstanding and world-class”.

The arrival of a new member, A. Boletti, has reinforced the group activities in flavour physics and in the exploration of the recent so-called flavour anomalies. P. Bargassa and A. Boletti have been appointed to coordination positions of CMS physics analysis working groups. J. Hollar, a senior researcher, together with T. Niknejad and K. Shchelina, two young researchers in the group, were awarded CMS prizes. These further attest the recognition of the group within the collaboration. A EU-funded project within the MSCA-RISE Horizon 2020 program, aMUSE, was approved and plans to strengthen and extend the collaboration between EU and US researchers to carry out searches for New Physics while promoting the development of next generation muon accelerators.

Sources of funding

PI	Code	Amount	Dates	Description
Michele Gallinaro	aAmuse - 101006726	115.000 €	--	aAmuse - advanced Muon Campus in US and Europe contribution
João Varela	CERN/FIS-INS/0032/2019	200.000 €	2019-08-01 / 2021-07-31	Collaboration in the Phase 2 Upgrade of the CMS experiment at CERN
Michele Gallinaro	CERN/FIS-PAR/0025/2019	200.000 €	2019-08-01 / 2021-07-31	Collaboration in the operation and physics data analysis at the CMS experiment at CERN

Total: 515.000 €

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 quark-gluon plasma and strong interactions, taking advantage of the collisions of lead 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) Operation and maintenance of the ECAL and PPS detectors:

The LIP/CMS group has members based at CERN who are required for the normal maintenance and operation of the ECAL and PPS sub-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). The activities are organized in two complementary projects:

- The project "Collaboration in the operation and physics data analysis at the CMS experiment at CERN". The project PI is Michele Gallinaro with Co-PI Nuno Leonardo.

- The project "Collaboration in the Phase-2 Upgrade of the CMS experiment at CERN". The PI is João Varela (40 years of research experience at CERN) with Co-PI Michele Gallinaro.

Senior researchers of the LIP/CMS group are: João Varela, João Seixas, Michele Gallinaro, Nuno Leonardo, Pedrame Bargassa, Jonathan Hollar, Pietro Faccioli.

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

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

The LIP 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)

- PPS DAQ Coordinator (Level-2), since 2015 (J. Hollar)

- Proton Physics Object Groups (POG) coordinator (Level-3), since 2019 (K. Shchelina)

- B-Physics Production and Properties coordinator (Level-3), since 2020 (A. Boletti)

- SUSY New analyses and trigger strategies coordinator (Level-3), since 2020 (P. Bargassa)

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

LIP group members participate in the following CMS structures:

- CMS Collaboration Board (M. Gallinaro and J. Varela)
- CMS Finance Board (J. Varela)
- CMS Publication Board (N. Leonardo, P. Faccioli)
- ECAL Executive Board (J.C. Silva)
- ECAL, MTD and HGCAL Institution Boards (J. Varela)
- PPS Institutions Board (M. Gallinaro)
- MTD Steering Committee (J. Varela)

Members of the LIP group are regularly selected to participate in Analysis Review Committees (ARC) and Detector Review Committees. Members of the LIP/CMS group convene the following weekly meetings of the CMS Collaboration: PPS Steering Committee, PPS DAQ meeting, Proton POG meeting, BTL electronics meeting, B-Physics Production and Properties meeting.

Assessment of the past year: objectives vs. achievements

Despite the difficult COVID-19 situation, there were no major deviations from the goals set for 2020.

Within the CMS experimental program, the LIP/CMS group made major scientific contributions in 2020 in the following areas:

1) Proton-proton physics

a) Top quark physics

Members of the group (PhD student A.Toldaiev, M.Gallinaro) had a leading role in the data analysis and preparation of the publication of 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 analysis was published. This work was the subject of the PhD thesis of A. Toldaiev who graduated with the highest marks ("distinction and honour", Oct. 2020).

Studies of lepton flavor universality in the same final state are continuing in collaboration with colleagues at IIT Madras. In a similar final state, a study of vector boson scattering (VBS) processes including a tau lepton using the full Run 2 data (student M.Magherini, M.Gallinaro) is pursued in the context of the VBSCan EU COST Action in collaboration with colleagues at Perugia.

b) Search for SUSY

The search for the 4-body decay of the lightest scalar top (stop) was performed in the Run 2 data by group members (PhD student D.Bastos, P.Bargassa) who developed a search based on an MVA approach. The analysis was presented at the internal CMS SUSY physics analysis meetings and it is in the final phase before the approval process by the collaboration.

c*) Search for double Higgs production*

Regression and classification studies in Higgs pair production were pursued in 2018-2019 with simulated CMS samples. Higgs pair production search in the "tautaubb" final state in the full Run 2 data is performed using advanced machine learning analysis techniques. Work is developed in the context of the Tau Id POG and Higgs HH working group. The analysis is entering the final phase before the approval process by the collaboration. Projections of the expected sensitivity developed for the Yellow Report were updated for different HL-LHC conditions. This activity was carried out in the framework of the EU Marie-Curie network AMVA4NewPhysics (PhD student G.Strong, M.Gallinaro). This was the subject of the PhD thesis of G.Strong who graduated with the highest marks ("distinction and honour", Dec. 2020).

d) Search for Dark Matter

Members of the LIP/CMS group (undergraduate student J.Goncalves, M.Gallinaro) pursued a search for Dark Matter (DM) 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, developed with the Run 2 data in collaboration with colleagues from Bari, was published.

e) Search for rare decays and measurement of heavy flavour

The study of rare decays with CMS data has remained a priority. The interest is reinforced by the large accumulated datasets and in particular by the so-called flavor anomalies (FA). The group is keeping its focus on the $b \to s\ell\ell$ FCNC transitions, at the core of the FA.

The group has carried out measurements of b-quark production and fragmentation, a crucial ingredient for the measurement of rare B decays, esp. $B \to \mu\mu$. These have been originally pursued in pp 13 TeV data (Master student B.Alves, N.Leonardo), and more recently with the 2017 dataset collected at 5TeV (Master student M.Faria, N.Leonardo) allowing to probe the energy dependence.

Another important decay realizing the $b \to s\ell\ell$ transition is $B \to K^*\mu\mu$. This is particularly pressing in view of reported departures from SM predictions that centrally contribute to the FA puzzle. The group is carrying out the analyses of the angular observables and rates (Master student M.Faria, A.Boletti, N.Leonardo) with the full Run2 data.

f) Quarkonia polarization

Members of the group (PhD student M.Araújo, P.Faccioli, J.Seixas), together with C. Lourenço (CERN) and T. Madlener (HEPHY) performed the first measurement of the polarizations of the χ_{c1} and χ_{c2} states, using CMS data.

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

Members of the group (J.Hollar, K.Shchelina) led the first analysis of dilepton production via two-photon interactions with tagged forward protons using the PPS spectrometer. Currently, members of the group are pursuing related analyses of two-photon production of tau lepton pairs (PhD student M. Pisano, M.Gallinaro, J.Hollar), W boson pairs (K.Shchelina, J.Hollar) and top quark pairs (PhD student M.Pisano, M.Gallinaro, J.Hollar) using PPS data.

2) Heavy-ion physics

B mesons as novel probes of QGP

The group is bringing unique expertise of B physics into the heavy ion realm, and has been playing a central part in the investigation of first B meson signals in PbPb data. The analysis of the PbPb 2015 data (Master student J.Silva, N.Leonardo) was released. The PbPb measurement includes contributions to leading systematic uncertainties (undergraduate students A.Pardal, J.Gonçalves). Studies towards the measurement of the nuclear modification factors are ongoing (students M.Faria, A.Semião, N.Leonardo). This work is in collaboration with the MIT group.

3) Experiment operation and maintenance

a) Physics objects development:

LIP members pursued the participation in the activities of POGs (Physics Object Groups), namely in the validation of the tau lepton reconstruction and identification (G.Strong, A.Toldaiev), forward proton alignment (G.Strong) and reconstruction efficiency (M.Pisano, K.Shchelina), and PPS high-level trigger (M.Araújo). Tag and probe tools for muon measurements with CMS open data were also developed (students A.Jales and T.Gaehtgens, with E.Melo, S.Fonseca, N.Leonardo).

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 from 2016-18 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 paper.

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 Tier2 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-2 upgrade carried by the group is organized in three areas:

a) R&D in the Barrel Timing Layer: Development of the frontend readout system of the timing detector (LYSO crystals and SiPMs) based on a fast-timing TOF ASIC provided by Portuguese industry (LIP full responsibility);

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

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

Some details:

a) Timing Detector

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 readout with silicon photomultipliers (SiPMs). The LIP group is responsible for the design and construction of the BTL readout system. One member of the group (J. Varela) 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 110 nm). 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 in February. In parallel, the TOFHIR2 Test Board (T2TB) was developed as well as an adapter for integration with the available standalone DAQ system. Tests started in July. Radiation resistance tests were performed in October at the x-ray irradiation facility at CERN (TID tests) and at the heavy-ion beam in Louvain (SEE tests). The results were published.

The ASIC design was reviewed in July by a committee of experts nominated by CMS. A new version (TOFHIR2X), implementing an improved version of the challenging circuitry to mitigate the effect of the large SiPM dark count noise due to radiation, was submitted in November.

The frontend (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. The first prototype of the Readout Unit based on TOFHIR1 was evaluated in 2020. Measurements with SiPM sensors and laser beams with two complete Readout Units showed excellent results. In parallel, an improved design of the Readout Unit based on TOFHIR2 was pursued in 2020. Prototypes are being fabricated for evaluation in 2021.

b) ECAL Readout System

The LIP/CMS group has an important role in the development and construction of the new ECAL FE Electronics System. The LIP contribution will build upon the long experience in the construction and operation of the current system, including the coordination of the ECAL Electronics.

The Portuguese industry was contracted to supply a high-performance ADC IP block featuring 12-bit, 160 MS/s and low power consumption. The first ADC design was already supplied and integrated by the INFN-Torino group in a CMOS 65nm chip that implements additional digital logic and data transmission (LiTE-DTU chip). In 2020 the tests of the LiTE-DTU integrated in the ECAL FE system were pursued.

c) High Granularity Calorimeter

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 drop LVR ASICs resistant to radiation with the performance required by HGCAL under a contract established with CERN. The evaluation of the LVR prototype chips was performed at CERN with excellent 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 of the HL-HLC. Results were presented at the HGCAL trigger group in 2020. 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 regularly take part in training and outreach activities for high school and university students (MasterClasses, CERN visits, InsideViews, and student sessions at LIP room at IST). In 2020, the group received 7 undergraduate and 2 high school student trainees. One group member (N. Leonardo) coordinates the LIP Internship Program and serves as co-coordinator of advanced training at LIP. Group members have been actively contributing to the Teachers School in Portuguese Language at CERN. In 2020, due to COVID-19 restrictions, some of these activities were reduced or took place in videoconference.

Lines of work and objectives for next year

The LIP/CMS group activities in 2021 will closely follow the research program of last year. The group plans to participate in the following areas of physics analysis and detectors activities:

Task 1: Physics analysis

1) Higgs physics

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

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

2) Electroweak physics

a) Measurement of the quartic gauge coupling ggWW using the PPS spectrometer;

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

3) B physics

Exploration of rare decays and flavour anomalies.

4) New physics in top like events

Studies of lepton flavor universality in top quark events and vector boson scattering processes with tau leptons in final state, and search for Dark Matter associated with the Higgs boson.

5) SUSY physics

Search for SUSY top squark in four-body decays.

6) Quarkonia

Precise measurements of the polarizations of J/psi and psi(2S).

7) Heavy-ion physics

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

Task 2: R&D Phase II Upgrade

1) 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.

2) R&D in the ECAL frontend 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 Portuguese industry.

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

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

Task 3: Experiment operation and maintenance

1) ECAL

Maintenance of the ECAL trigger and data acquisition system.

2) PPS

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

3) Physics objects development

Participation in the development and validation of the tau lepton and proton reconstruction in the framework of the corresponding Tau and Proton Physics Object Groups.

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

5) General

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

Medium-term (3-5 years) prospects

In the period 2021-25 the LIP/CMS group plans to keep the participation in the CMS experiment at the same high level of quality, responsibility and visibility. We plan to pursue the physics analyses of different topics profiting from the large amount of data expected until the end of Run 3. While definitive signs of New Physics haven't been yet revealed in the LHC data, the group will continue exploring the data to fully exploit the discovery opportunities offered by the LHC. The activity is organized in main physics domains, namely Higgs boson, Top quark, B mesons, Quarkonia, SUSY, PPS, and Heavy Ions, spanning from the search for new particles and phenomena beyond the Standard Model to precise measurements.

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

Finally, the group plans to remain strongly involved in the CMS Phase-II Upgrade for the High-Luminosity LHC (HL-LHC), developing microelectronics for the readout systems of the MIP Timing Detector (MTD), Electromagnetic Calorimeter, and High Granularity Calorimeter (HGCAL) in collaboration with Portuguese industry, and taking the leadership in the development of the MTD readout system.

- Physics

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

- Detector Operation and Maintenance

a) 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.

During Long Shutdown 2, all detector packages are being removed from the LHC tunnel, and replaced with new or refurbished detectors. Among the major changes, the timing detectors in Run 3 are planned to be based completely on double-diamond layers, and a second timing Roman Pot station will be added. The new PPS pixel tracking stations will be instrumented with piezoelectric motors, to allow mitigation of radiation damage via vertical movements of the sensors.

The PPS timing readout is based on HPTDC mezzanine cards, for which LIP has led the design and production. LIP will also contribute to the testing and characterization of the timing readout chain, as well as the online software for both the timing and pixel tracking detectors, and the development of new high-level triggers.

b) Electromagnetic Calorimeter

In the CMS operations in the period 2021-2025, the group plans to continue to be responsible for the operation and maintenance of the ECAL Data Acquisition and Trigger hardware.

- HL-LHC Phase-2 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-2 upgrade program to maintain the excellent performance of the detector.

The LIP participation in the CMS Phase-2 Upgrades is concentrated in the MIP Timing Detector (MTD) and in the ECAL and HGCAL Calorimeters. The generic goals of these upgrades are the following:

1. MIP Timing Detector: addition of a timing layer in front of the Calorimeters for precise timing measurement of all charged particles;
2. Electromagnetic Calorimeter: full replacement of the ECAL barrel electronics;
3. High Granularity Calorimeter: complete replacement of the Endcap calorimeters with a new high-granularity sampling calorimeter.

Participation in the upgrade of the PPS for the HL-LHC has also started with the LoI and will continue with the preparation of the Technical Design Report addressing specific physics and detector R&D studies.
The LIP/CMS group participation in the Phase-2 Upgrade reflects a close match and synergies between the historical role and technological expertise of the LIP group in the CMS experiment, the new opportunities offered by the Upgrade Projects, and the recognized world-wide leadership of Portuguese high-tech microelectronics companies in the domains relevant for the project.

SWOT Analysis

Strengths

Group well integrated in the collaboration. Several senior physicists with long experience in CMS and strong impact. Several coordination positions, including the leadership of the PPS sub-detector, convenership in physics and trigger groups, and the leading role in several physics analyses. Leadership in different areas of the front readout systems of the Phase-2 Upgrades.

Weaknesses

Difficulty in attracting and retaining national students, and difficulty in attracting researchers to Portugal. Lengthy and non-optimal evaluation process to award fellowships and/or long-term positions to outstanding candidates in HEP.

Opportunities

Opportunity of strong participation of Portuguese industry world leader in segments of microelectronics IP market in the CMS Phase-2 Upgrades for HL-LHC.

Threats

Unclear career prospects for several senior physicists of the group.

CMS

Publications

12 Articles in international journals
(with direct contribution from the team)

- *"Deep diffused APDs for charged particle timing applications: Performance after neutron irradiation"*, M. Gallinaro et al., Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 949 (2020) UNSP 162930
- *"On the impact of selected modern deep-learning techniques to the performance and celerity of classification models in an experimental high-energy physics use case"*, G. Strong, 2020 Mach. Learn.: Sci. Technol. 1, 045006
- *"Measurement of the top quark pair production cross section in dilepton final states containing one tau lepton in pp collisions at 13 TeV"*, CMS Collaboration (2307 authors), J. High Energy Phys. 2 (2020) 191
- *"Deep diffused Avalanche photodiodes for charged particles timing"*, M. Gallinaro et al., Nucl. Instr. Meth. 958 (2020) 162405 (arXiv:1903.07482)
- *"Timing performance of a Micro-Channel-Plate photomultiplier tube"*, M. Gallinaro et al., Nucl. Instr. Meth. 960, 21 April 2020, 163592 (arXiv:1909.12604)
- *"Constraints on the chi(c1) versus chi(c2) polarizations in proton-proton collisions at 8 TeV"*, CMS Collaboration (2284 authors), Phys. Rev. Lett. 124 (2020) 162002
- *"Measurement of properties of B(s)(0)s -> mu(+)mu(-) decays and search for B-0 -> mu(+)mu(-) with the CMS experiment"*, CMS Collaboration (2286 authors), J. High Energy Phys. 4 (2020) 188
- *"Measurement of B0s and B+ meson yields in PbPb collisions at sqrt(sNN)=5.02 TeV"*, CMS Collaboration, CMS-PAS-HIN-19-011
- *"Measurement of the CP-violating phase Phis in the B0s-> J/psiPhi(1020) ->mu+mu-K+K- channel in proton-proton collisions at 13 TeV"*, CMS Collaboration, arXiv:2007.02434 [hep-ex]
- *"Higgs boson potential at colliders: Status and perspectives"*, M. Gallinaro et al., Review in Physics 5 (2020) 100045
- *"Combination of the ATLAS, CMS and LHCb results on the B0(s)->mu+mu- decays"*, CMS and LHCb Collaborations, CMS-PAS-BPH-20-003
- *"Timing performance of a multi-pad PICOSEC-Micromegas detector prototype"*, M. Gallinaro et al., arXiv:2012.00545

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

- *"Observation of the Lambda(0)(b) -> J/psi Lambda phi decay in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2307 authors), Phys. Lett. B 802 (2020) 135203
- *"The Phase-2 Upgrade of the CMS Level-1 Trigger"*, CMS Collaboration, CERN-CMS-TDR-20-002, CERN-LHCC-2020-004
- *"Study of J/psi meson production from jet fragmentation in pp collisions at sqrt(s) = 8 TeV"*, CMS Collaboration, PLB 804 (2020) 135409
- *"Study of central exclusive pi(+)pi(-) production in proton-proton collisions at root s=5.02 and 13 TeV"*, A. M. Sirunyan et al. (2294 authors), Eur. Phys. J. C 80 (2020) 718
- *"Measurement of the Y(1S) pair production cross section and search for resonances decaying to Y(1S)mu(+)mu(-) in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2278 authors), Phys. Lett. B 808 (2020) 135578
- *"The very forward CASTOR calorimeter of the CMS experiment"*, CMS Collaboration, arXiv:2011.01185
- *"Measurement of B-c(2S)(+) and B-c*(2S)(+) cross section ratios in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2331 authors), Phys. Rev. D 102 (2020) 092007
- *"Measurement of single-diffractive dijet production in proton-proton collisions at root s=8 TeV with the CMS and TOTEM experiments"*, CMS Collaboration / TOTEM Collaboration (2398 authors), Eur. Phys. J. C 80 (2020) 1164
- *"Search for long-lived particles using displaced jets in proton-proton collisions at 13 TeV"*, CMS Collaboration, arXiv:2012.01581
- *"Search for bottom-type, vectorlike quark pair production in a fully hadronic final state in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2331 authors), Phys. Rev. D 102 (2020) 112004
- *"Search for a narrow resonance in high-mass dilepton final states in proton-proton collisions at 13 TeV"*, CMS Collaboration, CMS-EXO-19-019
- *"Measurement of the Z boson differential production cross section using its invisible decay mode (Z nu nu) in proton-proton collisions at 13 TeV"*, CMS Collaboration, arXiv:2012.09254
- *"Search for Heavy Resonances Decaying into a Photon and a Hadronically Decaying Higgs Boson in pp Collisions at root s=13 TeV with the ATLAS Detector"*, ATLAS Collaboration (2897 authors), Phys. Rev. Lett. 125 (2020) 251802

8 International Conference Proceedings

- *"Progress on the PICOSEC-Micromegas Detector Development: Towards a precise timing, radiation hard, large-scale particle detector with segmented readout"*, M. Gallinaro et al., Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 958 (2020) 162877
- *"HiggsML Lumin Code: supporting arXiv:2002.01427"*, G. Strong, 10.5281/zenodo.3754669
- *"Single photoelectron time resolution studies of the PICOSEC-Micromegas detector"*, M. Gallinaro et al., JINST 15(2020) 04, C04053
- *"Beyond the Standard Model in Vector Boson Scattering signatures"*, M. Gallinaro et al., arXiv:2005.09889
- *"Precise timing with the PICOSEC-Micromegas detector"*, M. Gallinaro et al., Nuovo Cim. C 43 (2020) 1
- *"Muon Energy Measurement from Radiative Losses in a Calorimeter for a Collider Detector"*, G. Strong et al., arXiv:2008.10958 [physics.ins-det]
- *"Search for new physics in b -> sl+l- transitions at CMS"*, A. Boletti on behalf of the CMS Collaboration, PoS(ICHEP2020)365
- *"TOFHIR2: The readout ASIC of the CMS Barrel MIP Timing Detector"*, J. Varela on behalf of the TOFHIR2 design team, CMS CR-2021/001

1 Proposal(s)

- *"The CMS Precision Proton Spectrometer at the HL-LHC - Expression of Interest"*, CMS Collaboration, CERN-CMS-NOTE 2020-008

9 Internal notes

- *"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
- *"Measurement of CP-violating phase phi c css in the Bs->J/psiK+K- channel using the 2017 and 2018 datasets"*, A. Boletti et al., CMS AN-2019/255
- *"Sensitivity study for the HH->bbtautau process at the High-Luminosity LHC"*, M. Gallinaro, M. Pisano, G. Strong, CMS AN-2020/161
- *"Exclusive WW and ZZ production in the fully hadronic channel with protons reconstructed in PPS"*, K. Shchelina, J. Hollar, et. al, CMS AN-2019/211
- *"Full angular analysis of decay B0 -> K*0 mu+ mu- at 13 TeV"*, A. Boletti et al., CMS AN-2018/138
- *"Lepton Flavour Universality in top quark events"*, O. Toldayev, M. Gallinaro, P. Silva, J. Varela, CMS AN-2020/005
- *"Search for anomalous couplings in exclusive WW production in the semileptonic channel using proton-tagged events from PPS"*, K. Shchelina, J. Hollar, et. al, CMS AN-2019/240
- *"Search for Higgs boson pairs produced through gluon and vector boson fusion in the bbtautau final state with Run-II data"*, M. Gallinaro, G. Strong, et al., CMS AN-2018/121
- *"Search for 4-body decays of stop in 1-lepton final states with a multivariate approach at Run II"*, P. Bargassa, D. Bastos, C. da Cruz e Silva, CMS AN-2019/276

2 Collaboration notes with internal referee

- *"Precision Proton Spectrometer timing detector efficiencies and two-arm timing resolution in 2018 data"*, CMS Collaboration, CERN-CMS-DP-2020-046
- *"Proton reconstruction with the Precision Proton Spectrometer (PPS) in Run 2"*, CMS Collaboration, CERN-CMS-DP-2020-047

Presentations

5 Oral presentations in international conferences

- G. Strong: *"Improvements to ML for searches at the LHC"*, 2020-07-28, ICHEP, Prague (Online)
- Alessio Boletti: *"Search for new physics in b to sl+l- transitions at CMS"*, 2020-07-30, ICHEP 2020, Prague, Czech Republic
- Thomas Gaehtgens: *"Efficiency studies using the Tag and Probe method"*, 2020-10-01, CMS Open Data Workshop for Theorists, Fermilab (Online)
- João Varela: *"TOFHIR2: The readout ASIC of the CMS Barrel MIP Timing Detector"*, 2020-10-31, 2020 IEEE Nuclear Science Symposium and Medical Imaging Conference, Boston, USA
- Mariana Araújo: *"Towards the understanding of quarkonium production through global-fit analyses of LHC data"*, 2020-11-13, XXXII International (ONLINE) Workshop on High Energy Physics "Hot problems of Strong Interactions, Online

13 Oral presentations in national or international meetings

- G. Strong: *"PyTorch Tutorial"*, 2020-02-10, IST's 6ªs Jornadas de Engenharia Física, IST, Lisbon
- Jonathan Hollar: *"CMS: The Precision Proton Spectrometer"*, 2020-02-14, LIP Jornadas, Braga
- Diogo de Bastos: *"CMS: Stop search"*, 2020-02-15, LIP Jornadas, Braga
- Tahereh Niknejad: *"The MIP Timing Detector for the CMS Phase-2 Upgrade"*, 2020-02-15, LIP Jornadas, Braga
- Nuno Leonardo: *"Overview of LIP-CMS group and rare processes"*, 2020-02-15, LIP Jornadas, Braga
- Nuno Leonardo: *"LIP Advanced Training and Internship Program"*, 2020-02-15, LIP Jornadas, Braga
- João Varela: *"From the LHC to the future: experimental perspective"*, 2020-09-28, Particle Physics for the Future of Europe, IST, Lisbon
- Nuno Leonardo: *"Flavour and beyond Standard Model physics"*, 2020-09-28, Particle Physics for the Future of Europe, IST, Lisbon
- Michele Gallinaro: *"Physics goals at the LHC"*, 2020-10-09, CMS day@IST 2020, IST, Lisbon (online)
- João Varela: *"Detector upgrades and plans for the High-Luminosity LHC"*, 2020-10-09, CMS Day @ IST, IST, Lisbon
- Nuno Leonardo: *"The CMS experiment at CERN's LHC: an overview"*, 2020-10-09, CMS Day @ IST, IST, Lisbon
- Jonathan Hollar: *"Ongoing activities at CERN: Connection from the CERN laboratory"*, 2020-10-09, CMS day @IST, online
- João Varela: *"BTL electronics / ASICs"*, 2020-11-04, P2UG in-depth review of MTD, CERN

2 Poster presentations in national or international meetings

- Hilberto Silva: *"Physics with forward protons with the CMS experiment"*, 2020-09-28, Particle physics for the future of Europe, IST, Lisbon
- Diogo de Bastos: *"Prospects at the High-Luminosity LHC with the CMS experiment"*, 2020-09-28, Particle physics for the future of Europe, IST, Lisbon

1 Presentation(s) in national conference(s)

- Matteo Pisano: *"Study of central exclusive production of top quark-antiquark pairs at LHC."*, 2020-09-14, 106th SIF national congress, Online

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

- Thomas Gaehtgens: *"Study of the efficiency of muon identification algorithm with Tag and Probe method using CMS Open Data"*, 2020-09-03, Fisica 2000, Online

25 Oral presentations in advanced training events

- Michele Gallinaro: *"The experimental program at the LHC"*, 2020-01-21, Doctorate Course at Bari, Italy
- Michele Gallinaro: *"Probing the Standard Model at the LHC"*, 2020-01-22, Doctorate Course at Bari, Italy
- Michele Gallinaro: *"The Top quark"*, 2020-01-23, Doctorate Course at Bari, Italy
- Michele Gallinaro: *"Top quarks and beyond"*, 2020-01-24, Doctorate Course at Bari, Italy
- Michele Gallinaro: *"The Standard Model Higgs and beyond"*, 2020-01-29, Doctorate Course at Bari, Italy
- Michele Gallinaro: *"Exotica and Dark Matter searches"*, 2020-01-30, Doctorate Course at Bari, Italy
- Michele Gallinaro: *"New physics searches at LHC: Looking forward and beyond"*, 2020-02-07, Fifth Lisbon mini-school on Particle and Astroparticle Physics, Caparica, Portugal
- João Varela: *"Experimental program at the LHC"*, 2020-03-02, Course on Physics at the LHC, LIP, Lisbon
- João Varela: *"Standard Model at the LHC"*, 2020-03-06, Course on Physics at the LHC, LIP, Lisbon
- Diogo de Bastos: *"Search for the Supersymmetric partner of the top quark at the LHC with a multivariate approach"*, 2020-03-09, CAT (Commissao Acompanhamento Tese) presentation , LIP, Lisbon
- Michele Gallinaro: *"Top quark: Introduction"*, 2020-03-23, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: *"Top quark: Properties and beyond"*, 2020-03-24, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: *"Higgs boson: Beyond the SM searches"*, 2020-04-15, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: *"Exotic processes and Dark Matter"*, 2020-04-27, Course on Physics at the LHC, LIP, Lisbon
- Nuno Leonardo: *"Rare decays of Standard Model particles"*, 2020-04-29, Course on Physics at the LHC, online
- João Varela: *"Future endeavors"*, 2020-05-06, Course on Physics at the LHC, LIP seminar, LIP, Lisbon
- G. Strong: *"Neural Networks on a budget"*, 2020-06-25, 6th LIP PhD Workshop, Online
- Diogo de Bastos: *"High-performance timing detector for the HL-LHC Upgrade of the CMS experiment at CERN"*, 2020-06-26, 6th IDPASC/LIP Students Workshop, Online
- Mariana Araújo: *"Constraints on the chi_c1 and chi_c2 polarizations"*, 2020-06-26, 6th IDPASC/LIP PhD Students Workshop, Online
- João Varela: *"The LHC experimental program"*, 2020-07-14, LIP Internship tutorial week, online
- Nuno Leonardo: *"Tutorial chats: LHC and QGP"*, 2020-07-14, LIP Internship tutorial week, online
- João Varela: *"Preparar o futuro: a estratégia europeia na Física de Partículas"*, 2020-09-03, FÍSICA 2020, IEUL, Lisboa
- Nuno Leonardo: *"LIP Internship Program, 4th edition closing"*, 2020-09-11, LIP Internship Workshop, Online
- Nuno Leonardo: *"Data analysis / fitting tutorial"*, 2020-09-11, LIP Internship tutorial week, online
- Mariana Araújo: *"Quarkonium production at LHC energies: understanding hadron formation by the strong force"*, 2020-09-29, Presentation to the CAT, Online

3 Seminars

- Michele Gallinaro: *"Looking forward: The Precision Proton Spectrometer"*, 2020-02-13, Seminar, Louvain-la-Neuve, Belgium
- G. Strong: *"Improvements to ML for searches at the LHC"*, 2020-05-20, DMML Colloquia, Online
- João Varela: *"European Strategy for Particle Physics"*, 2020-07-30, CFTP seminar, IST, Lisbon

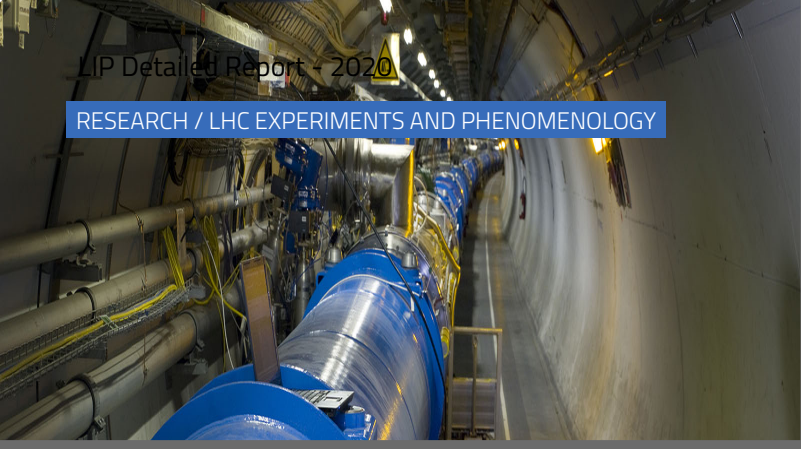
Theses

5 PhD

- Oleksii Toldaiev: *"Top quark physics and search for physics beyond the Standard Model at the Large Hadron Collider"*, 2013-12-01 / 2020-10-29, (finished)
- Giles Strong: *"Deep Learning methods applied to Higgs physics at the LHC"*, 2016-05-16 / 2020-12-22, (finished)
- 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)

1 Master

- Maria Faria:*"Measurement of B meson production and flavour anomalies"*, 2020-09-14 , (ongoing)



PHENO

Phenomenology

Principal Investigator:
Guilherme Milhano (100)

16 ***Researcher(s):***
António Onofre (60), Carlota Casas (33), Filipa Peres (100), Filipe Veloso (20), Grigorios Chachamis (100), Helmut Wolters (7), João Nuno Pires (100), João Seixas (5), Liliana Apolinário (85), Miguel Fiolhais (60), Miguel Romão (100), Nuno Castro (45), Pietro Faccioli (50), Ricardo Gonçalo (20), Ruben Conceição (12), Susana Coito (8)

1 ***Technician(s):***
Henrique Carvalho (10)

4 ***PhD Student(s):***
Guilherme Guedes (100), Maria Ramos (100), Mariana Araújo (43), Susana Santos (100)

6 Master Student(s):
André Cordeiro (25), André Reigoto (100), António Oliveira (25), João Martins da Silva (100), Maura Teixeira (14), Pedro Lagarelhos (50)

3 ***Trainee(s):***
Ema Mendes, Marcelo Gonçalves, Sara Peça

1 ***Undergraduated Students:***
João Moreira

17 ***External collaborator(s):***
Alessandro Broggio, Andrea Ferroglia, André Pereira, Artur Amorim de Sousa, Bruno Miguel Silva, Carlos Lourenço, Francisco del Aguila Giménez, José Santiago Perez, João Lopes, João Lourenço Barata, João Pedro Gonçalves, Juan Antonio Aguilar Saavedra, Korinna Zapp, Mikael Chala, Orlando Oliveira, Paulo J. Silva, Rui Santos

Total FTE:
15.7

Articles in international journals:	**15** Direct contribution
Students notes:	**1**
International conferences:	**12** Oral presentations **4** Proceedings
International meetings:	**4** Oral presentations
Collaboration meetings:	**1** Oral presentation
Seminars:	**8** Seminars **1** Outreach seminar
Completed theses:	**2** Masters

Executive summary

LIP's Phenomenology group conducts research bridging theory and experiment in particle and astroparticle physics. Its research, while independent, 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 quarkonium production measurements made by LIP's CMS group and their phenomenological interpretation in our group, and several symbiotic projects (in New Physics searches and jet quenching studies) with the Competence Center on Simulation and Big Data.

Over the last year, a larger number of students (internships, Master and PhD) have chosen the group to further their training. The members of the group have maintained their excellent publication record and high international visibility. The group continues its sustainable path of development and relevance both within and outside LIP.

Sources of funding

PI	Code	Amount	Dates	Description
Pietro Faccioli	CERN/FIS-PAR/0015/2017	10.000 €	2017-11-01 / 2020-08-31	Heavy Quarkonium production in hadronic interactions at LHC and AFTER@LHC
Guilherme Milhano	CERN/FIS-PAR/0022/2017	30.000 €	2018-03-01 / 2020-02-29	Jets as quark gluon plasma probes
Guilherme Milhano	824093 - STRONG-2020	188.500 €	2019-06-01 / 2023-05-31	The strong interaction at the frontier of knowledge:fundamental research and applications
Guilherme Milhano	835105 - YoctoLHC	399.062 €	2019-10-01 / 2024-09-30	Yoctosecond imaging of QCD collectivity using jet observables
António Onofre	CERN/FIS-PAR/0029/2019	45.000 €	2019-11-15 / 2021-11-14	Estudos fenomenológicos em LHC na fisica de quarks top e bosões de Higgs
Guilherme Milhano	CERN/FIS-PAR/0024/2019	90.000 €	2020-07-01 / 2022-06-30	Bridging Theory and Experiment: Collider Phenomenology
Pietro Faccioli	CERN/FIS-PAR/0010/2019	20.000 €	2020-09-01 / 2022-08-31	Methods for Understanding Strong Interactions with Quarkonia

Total: 782.562 €

Pheno

Overview

At present the group has internationally recognized consolidated research activities in top-quark, Higgs, Dark Matter searches, quarkonia, precision QCD, and heavy-ion phenomenology with a strong expertise in the development of event-generators. The group has placed an increasing effort on the exploration of physics opportunities in future collider facilities. The close connection between work on simulation of cosmic ray air showers carried out in other groups and our QCD activities continues to be explored.

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 many students being trained in the group. While group members enjoy freedom of focus for their work, ongoing discussions are leading 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 main objectives for 2020 were:

- hiring of a number of postdoctoral researchers for a sustained growth strategy;
- identification of future areas of expansion on Beyond the SM (BSM) and QCD precision physics analysis;
- prioritise efforts on data-driven/model-independent studies in the areas of top-quark, Higgs, quarkonia, precision QCD, and heavy-ion phenomenology, with a particular focus to harness the full potential of the next phases of the LHC (high-luminosity runs and lighter-than-Lead ions);
- continue the consolidated collaboration work with the Simulation and Big Data competence centre;
- exploration of possible synergies with the cosmic ray experimental groups and the nuclear physics and strong interaction group NPStrong that joined LIP last year.

During 2020:

- a postdoctoral researcher, working in heavy-ion phenomenology, was hired. Collaboration with other group members has already resulted in one publication, with other projects ongoing;
- two further selection procedures for postdoctoral researchers have been concluded for contracts starting during 2021;
- synergies with the Simulation and Big Data competence centre continue to deliver significative results: two works were submitted and accepted for publication, and the project to distinguish jets modified by their propagation in a QGP and their vacuum counterparts using image processing techniques has come to fruition and will soon be submitted for publication;
- while COVID-19 travel restrictions severely limited participation in international conferences and workshops, group members continued to deliver several conference talks, several of which by invitation;
- two Master students successfully defended their theses;
- group members lead the work package on jet studies in the European Consortium STRONG2020;
- the impossibility of in-person meetings has delayed progress in establishing synergies with cosmic ray experimental groups and the NPStrong group.

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

Lines of work and objectives for next year

The increase of Master and PhD students and postdoctoral researchers places the group on a path of steady growth. We expect this will contribute to a significant increase in output and international visibility in the different areas covered by our research programme.

We will focus on the existing consolidated areas, that already proved 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.

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.

Medium-term (3-5 years) prospects

To fulfil 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 important 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.

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; below target number of doctoral students.

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 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 European funding.

Threats

Uncertainty in ability to retain current precariously employed researchers; competition with international centres of excellence offering better medium/long term prospects for hiring new researchers; strong dependence on funding agency's irregular timeframes for hiring experienced researchers (one researcher awarded a 6-year contract to join the group declined contract because of not being able to wait for final decision from funding agency)

Pheno

Publications

15 Articles in international journals
(with direct contribution from the team)

- *"Mapping collinear in-medium parton splittings"*, F. Domínguez, J. G. Milhano, C. A. Salgado, K. Tywoniuk, V. Vila, Eur.Phys.J. C80 (2020) no.1, 11
- *"Modification of Jet Substructure in Heavy Ion Collisions as a Probe of the Resolution Length of Quark-Gluon Plasma"*, J. Casalderrey-Solana, G. Milhano, D. Pablos and K. Rajagopal, JHEP 2001 (2020) 044
- *"Jet cross sections at the LHC and the quest for higher precision"*, Johannes Bellm, Andy Buckley, Xuan Chen, Aude Gehrmann-De Ridder, Thomas Gehrmann, Nigel Glover, Alexander Huss, Joao Pires, Stefan Höche, Joey Huston, Silvan Kuttimalai, Simon Plätzer, Emanuele Re, Eur.Phys.J. C80 (2020) no.2, 93
- *"Transferability of Deep Learning Models in Searches for New Physics at Colliders"*, M. Crispim Romao, N. F. Castro, R. Pedro, T. Vale, Phys. Rev. D 101 (2020) 035042
- *"Study of interference effects in the search for flavour-changing neutral current interactions involving the top quark and a photon or a Z boson at the LHC"*, Maura Barros, Nuno Filipe Castro, Johannes Erdmann, Gregor Gebner, Kevin Kroninger, Salvatore La Cagnina, Ana Peixoto, Eur. Phys. J. Plus 135 (2020) 339
- *"A semi-infinite matrix analysis of the BFKL equation"*, N. Bethencourt de León, G. Chachamis, A. Romagnoni and A. Sabio Vera, Eur. Phys. J. C 80, no.6, 549 (2020)
- *"Novel Interpretation Strategy for Searches of Singly Produced Vector-like Quarks at the LHC "*, Avik Roy, Nikiforos Nikiforou, Nuno Castro, Timothy Andeen, Phys. Rev. D 101 (2020) 115027
- *"Medium-induced gluon radiation with full resummation of multiple scatterings for realistic parton-medium interactions"*, C. Andrés, L. Apolinário, F. Dominguez, JHEP 07 (2020) 114
- *"On the breaking of Casimir scaling in jet quenching"*, L. Apolinário, J. Barata, J. G. Milhano, Eur. Phys. J. C 80, 586 (2020)
- *"From prompt to direct J/psi production: new insights on the chi(c1) and chi(c2) polarizations and feed-down contributions from a global-fit analysis of mid-rapidity LHC data"*, Pietro Faccioli, Carlos Lourenco, Thomas Madlener, Eur. Phys. J. C 80 (2020) 623
- *"Composite dark matter phenomenology in the presence of lighter degrees of freedom"*, Maria Ramos, J. High Energ. Phys. 2020, 128 (2020)
- *"Phenomenology of NNLO jet production at the LHC and its impact on parton distributions"*, Rabah Abdul Khalek, Stefano Forte, Thomas Gehrmann, Aude Gehrmann-De Ridder, Tommaso Giani, Nigel Glover, Alexander Huss, Emanuele R. Nocera, Joao Pires, Juan Rojo, Giovanni Stagnitto, Eur. Phys. J. C 80, 797 (2020)
- *"Effective field theory for vector-like leptons and its collider signals"*, Mikael Chala, Paweł Kozów, Maria Ramos, Arsenii Titov, Physics Letters B 809 (2020) 135752
- *"Novel flavour-changing neutral currents in the top quark sector"*, Nuno Castro, Mikael Chala, Ana Peixoto, Maria Ramos, JHEP 2020 (2020) 38
- *"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

4 International Conference Proceedings

- *"Jets in QCD matter: Monte Carlo approaches"*, Liliana Apolinário, PoS HardProbes2018 (2019) 022
- *"Time evolution of a medium-modified jet"*, L. Apolinário, PoS EPS-HEP2019 (2020) 296
- *"Road map to extracting medium properties: an overview"*, L. Apolinário, Nucl.Phys.A 1005 (2021) 121983
- *"Impact of LHC jet data on Parton Distribution Functions"*, João Pires, PoS LHCP2020 (2021) 145

Presentations

12 Oral presentations in international conferences

- Maria Ramos: *"Novel B-decay signatures of light scalars at high energy facilities"*, 2020-02-17, STEALTH physics at the LHCb, Santiago de Compostela, Spain
- João Pires: *"Impact of LHC jet data on Parton Distribution Functions"*, 2020-05-27, LHCP2020, (online)
- Guilherme Milhano: *"Future Facilities: FCC and related subjects (invited plenary)"*, 2020-06-05, Hard Probes 2020, online
- Grigorios Chachamis: *"Mueller-Navelet jets"*, 2020-07-15, EF06 meeting: Low x, BFKL, online
- Miguel Romão: *"Deep Learning Versatility in New Physics Searches"*, 2020-07-31, ICHEP 2020, remote
- Maria Ramos: *"Non-minimal composite dark matter"*, 2020-09-22, LIO international conference on composite connections, online
- Pietro Faccioli: *"Charmonium polarization in pp collisions"*, 2020-10-01, Workshop "Gluon content of proton and deuteron with the Spin Physics Detector at the NICA collider", JINR, Dubna - online
- Grigorios Chachamis: *"Mueller-Navelet jets phenomenology"*, 2020-11-09, Forward Physics Facility - Kickoff Meeting, online
- Grigorios Chachamis: *"Further thoughts & Discussion on the Implications for Parton Distribution session (invited summary)"*, 2020-11-10, Forward Physics Facility - Kickoff Meeting, online
- Mariana Araújo: *"Towards the understanding of quarkonium production through global-fit analyses of LHC data"*, 2020-11-13, XXXII Int. Workshop on HEP "Hot problems of Strong Interactions", Protvino, Russia (online)
- Pietro Faccioli: *"The fate of quarkonia in heavy-ion collisions at LHC energies: a unified description of the sequential suppression patterns"*, 2020-11-13, XXXII Int. Workshop on HEP "Hot problems of Strong Interactions", Protvino, Russia (online)
- Pietro Faccioli: *"J/psi production and polarization in pp collisions"*, 2020-11-17, 17th International Workshop on Hadron Structure and Spectroscopy (IWHSS 2020), Trieste, Italy - and online

4 Oral presentations in national or international meetings

- Miguel Romão: *"Deep Learning as a Tool for Generic Searches at Colliders"*, 2020-07-07, IML Machine Learning Working Group Meeting, CERN, Geneva
- Liliana Apolinário: *" Fixed target & Heavy-Ions"*, 2020-09-28, Particle Physics for the Future of Europe, IST, Lisbon, Portugal

- Nuno Castro: *"Global EFT efforts: fits and related systematics"*, 2020-10-20, 1st General Meeting of the LHC EFT Working Group, virtual world
- Liliana Apolinário: *" Energy loss beyond multiple soft or single hard approximations"*, 2020-10-22, 2020 RHIC/AGS Annual Users Meeting, Online

8 Seminars

- Maria Ramos: *"Phenomenology of non-minimal composite Higgs models"*, 2020-02-06, Seminario del Dpto. Física Teórica y del Cosmos, Granada, Spain
- Liliana Apolinário: *" Time structure of QGP using top quarks in PbPb collisions"*, 2020-02-13, , IPN Orsay, France
- Miguel Romão: *"Searching for Rare Events at Colliders Using Deep Learning"*, 2020-06-19, Friday Seminar - Southampton High Energy Physics Group, Southampton, United Kingdom
- Miguel Romão: *"Searching for Rare Events at Colliders Using Deep Learning"*, 2020-07-02, LIP Thursday Seminar, remote
- Carlota Casas: *"Full resummed medium-induced radiation spectrum"*, 2020-09-16, , University of Urbana Champaign, Illinois (USA) (online)
- Guilherme Milhano: *"Probing the Quark Gluon Plasma with jets"*, 2020-10-21, , Seminarium Zakładu Fizyki Teoretycznej, NCBJ Warsaw (online)
- Carlota Casas: *"Simultaneous QCD analysis of collinear distributions"*, 2020-10-8, , LIP, Lisbon (online)
- Carlota Casas: *"Fully resummed medium-induced gluon radiation and the importance of multiple scatterings"*, 2020-11-30, , Department of Theoretical Physics, CERN, Geneva (online)

1 Outreach seminar(s)

- Liliana Apolinário: *" Recriar o Big Bang em Laboratório"*, 2020-02-12, XXIII Semana da Física, IST, Lisbon, Portugal

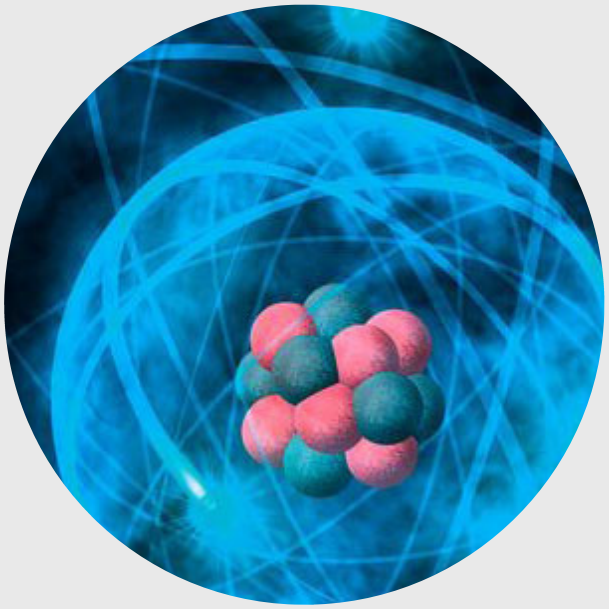
Theses

3 PhD

- Mariana Araújo: *"Quarkonium production studies at LHC energies: towards the understanding of bound-state formation by the strong force"*, 2018-02-12 , (ongoing)
- Maria Ramos: *"Interplay between collider and astrophysical signals of non-minimal composite Higgs models"*, 2017-11-15 , (ongoing)
- Guilherme Guedes: *"Collider and astrophysical constraints to little Higgs models"*, 2018-11-13 , (ongoing)

4 Master

- Maura Teixeira: *"Search for Dark Matter in Monotop Events at the Large Hadron Collider"*, 2018-10-01 / 2020-11-19, (finished)
- João Martins da Silva: *"Space-Time Structure of QCD jets"*, 2019-11-20 / 2021-01-28, (finished)
- António Oliveira: *"Unsupervised machine learning techniques in high energy physics"*, 2020-09-08 , (ongoing)
- André Cordeiro: *"Towards the space-time picture of a QCD parton shower"*, 2020-09-01, (ongoing)



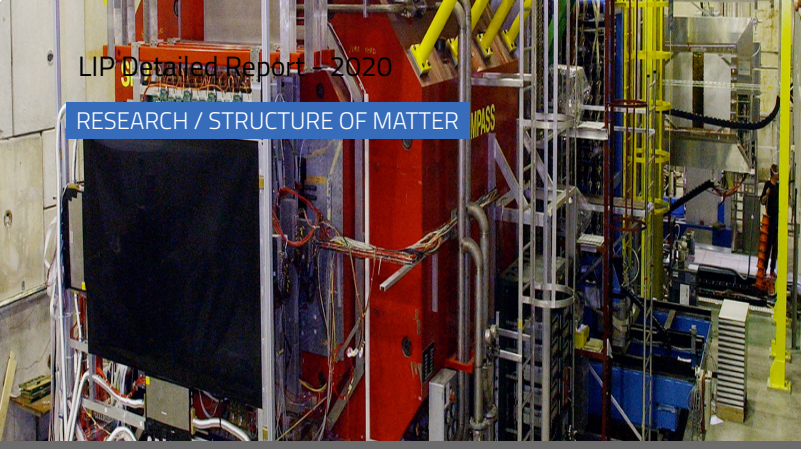
[Structure of matter]

Partons and QCD

HADES

NUC-RIA

NPStrong



PARTONS AND QCD

Participation in the COMPASS and AMBER experiments at CERN

Principal Investigator:
Catarina Quintans (100)

4 ***Researcher(s):***
Celso Franco (22), Marcin Stolarski (80), Márcia Quaresma (100), Pietro Faccioli (25)

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

3 ***Trainee(s):***
Adriana Monteiro, Gabriel Lourenço, Maria Francisca Queiros

1 ***Undergraduated Student(s):***
Rita Silva

2 ***External collaborator(s):***
Catarina Corte-Real, Francisco Feliciano

Total FTE:
4.3

Articles in international journals:
2 Direct contribution
4 Indirect contribution
Students notes:
1
International conferences:
6 Oral presentations
International meetings:
1 Oral presentation
1 Poster
Collaboration meetings:
9 Oral presentations
Advanced Training Events:
3 Oral presentations

Executive summary

The COMPASS Experiment at CERN enters its last data-taking campaign in 2021/2022, with Deep Inelastic Scattering (DIS) measurements of a muon beam off a transversely polarized deuteron target. This measurement will provide unprecedented accuracy on the d-quark tensor charge knowledge, similar to that already obtained for the u-quark. The accuracy on the d-quark PDF (parton distribution functions), namely Sivers and transversity, is expected to improve by more than a factor two with one year of physics data taking. The 2019/2020 Long Shutdown at CERN provided the opportunity for preparing the 2021 Run. The LIP group implemented important upgrades of the Detector Control System (DCS), namely the integration of the new HV and LV units. A large-scale testing of the whole experimental setup was done in November/December 2020 (COMPASS Dry Run 2020), with the in-person participation of Christophe Pires, responsible for the DCS, and remote shifts done by two other members of the group.

The COMPASS analysis activities of the group included the kaon and proton multiplicity ratio measurement from deuteron target in DIS, the pion-induced Drell-Yan (DY) cross-section measurement, and the hadron beam particle identification studies using CEDARs. The first one was completed and the respective article, which has Marcin Stolarski as corresponding author, was published in 2020. The second is an analysis coordinated by Catarina Quintans (who is also one of the analysts), it is ongoing and results are expected to be released during 2021. The third analysis, considered crucial for the feasibility proof of future Drell-Yan AMBER measurements, is being done by Márcia Quaresma and Marcin Stolarski. Another analysis that was ongoing in the first part of 2020, the application of machine learning techniques to physics process separation in the Drell-Yan sample, had promising preliminary results but had to be postponed. These studies were developed by Celso Franco, who left LIP during the Summer, and there is presently no human power in the group to proceed with the activity.

The AMBER Scientific Proposal for Phase-I measurements was extensively discussed with CERN SPSC referees during 2020, with important participation by Márcia Quaresma, Pietro Faccioli and Catarina Quintans. A series of Theory/Experiment workshops discussing the main physics topic at AMBER, the Emergence of Hadron Mass, was co-organized by Catarina Quintans. Four editions took place since December 2019, all held by video-conference. The Phase-I proposal of AMBER was approved by the CERN Research Board on December 2nd 2020. The participation of the LIP group in AMBER was approved by the LIP Scientific Council four days later. Márcia Quaresma was appointed as co-coordinator of the Drell-Yan Physics group of AMBER. The group is involved in the Drell-Yan physics simulations at AMBER, and recently integrated three Master students who will contribute to this and to COMPASS analyses as well. The group intends to take the co-responsibility for the DCS of AMBER, in cooperation with another group.

Sources of funding

PI	Code	Amount	Dates	Description
Catarina Quintans	CERN/FIS-PAR/0022/2019	155.000 €	2019-09-01 / 2021-08-31	Collaboration in the COMPASS and AMBER experiments at CERN

Total: 155.000 €

Partons and QCD

Overview

The LIP group "Partons and QCD" participates in the COMPASS experiment at CERN since 2003, and also participates in the recently approved AMBER experiment. The group has technical expertise in Detector Control Systems, C. Pires being the responsible for the DCS of COMPASS.

The main activity of the group is data analysis. C. Quintans is the coordinator of the COMPASS Drell-Yan physics group, while M. Quaresma is co-coordinator of the Drell-Yan physics group of AMBER. P. Faccioli, expert in phenomenological studies of Quarkonium, is giving support to the J/psi studies in COMPASS. M. Stolarski plays a leading role in the COMPASS analyses related to hadron multiplicities. In parallel, he pursues several applications of deep neural network methods: in the optimization of RICH particle identification, and trying to establish a new method for CEDARs beam particle identification.

The group is strongly involved in the preparation of the new AMBER experiment, by performing physics simulations, and in proposal writing and discussions. The AMBER project extends 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.

Assessment of the past year: objectives vs. achievements

One of the main goals for 2020 was the release of Drell-Yan differential cross sections, with an expected significant impact in the pion PDFs extraction and the study of cold nuclear matter effects. This goal was not yet achieved. Non-negligible discrepancies of the Monte Carlo with real data were identified, that motivated a mandatory but very time-consuming detailed MC description of the trigger system. The lack of human power is one of the difficulties faced in this analysis, reason why C. Quintans, who coordinates the Drell-Yan physics group, is now also one of the main analysts. Meanwhile, a reproduction of the 2018 data was also started, to take advantage of several improvements at the level of the reconstruction method. The Drell-Yan target transverse spin asymmetries study from 2018 data, done by M. Quaresma, will be resumed once the data reproduction is completed. Another analysis that was ongoing was the development of a new method of signal from background separation based on deep neural networks, by C. Franco. Although he obtained encouraging preliminary results (corresponding to a statistical gain by 15% in the DY TSAs analysis), the analysis was stopped in the Summer, since this researcher left LIP.

Another main goal for 2020 was the publication of the antiproton to proton and K- to K+ multiplicity ratios from deuteron target data, which was accomplished in July. This analysis was done by M. Stolarski, who is corresponding author of the paper. The main outcome is a large discrepancy observed between the measured ratios and the pQCD predictions.

A most relevant achievement in 2020 was the approval of the AMBER Phase-I by the CERN Research Board. The group devoted a lot of effort to the feasibility studies of this project, the writing of the proposal and follow-up the answers to the referees from the SPS and PS Experiments Committee (SPSC) and the Physics Beyond Colliders Committee (PBC). Radiation environment simulations using the FLUKA package were performed by M. Quaresma. Simulations of the vertex detectors to be used in Phase-I, and the reconstruction of respective MC data were done by C. Franco. Physics simulations for AMBER were done by C. Quintans. Finally, the beam particle identification by CEDARs was studied by M. Quaresma, and later on by M. Stolarski, using data collected by COMPASS in 2018. The latest results show a good CEDARs efficiency for kaon identification, above 90% per PMT, even at the nominal beam intensity of 7×10^7 particles/second, proving that the upgrade done on the CEDAR PMTs, thermalization and front-end electronics was effective. On the other hand, this study has shown that the beam reconstruction accuracy is an important limiting factor to the particle identification. A requirement for AMBER was thus identified, to improve the angular resolution in the beam telescope, from the present 50 microradians to < 20 microradians.

Finally, several aspects of the DCS of COMPASS were upgraded during 2020, profiting from the Long Shutdown period at CERN, in 2019/2020. The planned software upgrades were implemented. Part of the work suffered some delay due to the pandemic situation. The presence of the DCS responsible C. Pires on-site, during the entire year, was crucial for the collaboration, to guarantee the safety and maintenance of critical systems of the polarized target. In November/December there was a test data taking (Dry Run 2020), when detectors were switched on and the DCS and DAQ were successfully tested.

Lines of work and objectives for next year

The LIP group plans to proceed with the same lines of work explored so far.

In what concerns Drell-Yan data, the group will contribute to the ongoing analyses, namely in the aspects of: coordination, co-supervision, and analysis. The COMPASS Drell-Yan subgroup is coordinated by Catarina Quintans who follows all the DY and charmonium analyses, and participates directly in the DY cross-sections measurement. One of the goals for 2021 is to have these results released during this year. The DY transverse spin asymmetries analysis from the full 2018 data set by Márcia Quaresma (among others) shall continue, once the data re-processing is completed.

The recent changes in the available human power of the group, that counts presently one less researcher (and has a second researcher in maternity leave during the first 5 months of the year), but three

additional students, motivates that training becomes one important task assumed by the group. The new students will learn the basics of Drell-Yan physics and of this process as a tool to study non-perturbative QCD, how to use the COMPASS and AMBER software, and how to program their own analysis codes. These masters students will be fully integrated in the group and shall contribute in the COMPASS and AMBER analyses.

The preparation of the scientific proposal for the Phase-II of AMBER, using radio-frequency separated kaon and antiproton beams, is another task in which the group is involved. Pietro Faccioli plans to work on charmonium polarization predictions specific for the AMBER measurements with kaon beams, one of the topics addressed by that proposal. The analysis of CEDARs data collected in 2018 by COMPASS shall proceed in 2021 by Marcin Stolarski. The beam particle identification by CEDARs is crucial for the feasibility of the planned measurements. The encouraging results obtained so far is motivating a further study, on the potential of using neural networks for pattern recognition in CEDARs particle identification detectors (PID).

The data collected in 2016 and 2017 by COMPASS using muon beams of both charges is being studied by Marcin Stolarski, who focuses on the hadron multiplicities and fragmentation functions (FFs). Large impact is expected from these data sets, collected on a liquid hydrogen target, whose results from the theoretical point of view are much easier to interpret than those previously studied (using a ^{6}LiD target). The LIP team leads the COMPASS studies on charged kaon, pion and proton multiplicity ratios.

COMPASS will start its 2021 data-taking campaign only in July, due to the CERN accelerator intervention delays caused by the COVID-19 pandemic. The 2021 Run will be devoted to the DIS measurements using a muon beam scattering off a transversely polarized deuteron target. To achieve the statistical goal established, the data taking will have to continue still in 2022. The DCS of COMPASS, which is responsibility of the LIP group, will complete its upgrade tasks until July: full integration of all the new CAEN HV units purchased to replace obsolete and faulty ones; integration of new LV units; change over to a new technology of CAN interface cards (ANAGATE); change over to CAN and CAEN OPC-UA control software; addition of monitoring sensors for the TPC and Silicon detectors of the proton radius measurement pilot Run. Once the data taking starts, the group will provide on-call support to the DCS. This important task is guaranteed almost entirely by only one expert in place, Christophe Pires. The group will also do its part of shifts during the data taking period (typically 6 per researcher).

Medium-term (3-5 years) prospects

The medium-term prospects for the group are to conclude the COMPASS data analyses which 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, by mid-2022, 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 inherit parts of 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. These measurements may start in 2024, and require a novel vertex detector concept, and a more precise beam reconstruction. In the short and mid term, the group is involved in defining the requirements for these detectors, and producing the Monte-Carlo studies for this new setup.

SWOT Analysis

Strengths

Members of the LIP group are responsible for several analyses and coordinate physics groups in both COMPASS and AMBER. The group is also responsible for the DCS, a field in which it has recognized expertise, and cooperates with the CERN Controls and Automation groups in the testing of new hardware solutions and in the development of new software implementations.

Weaknesses

The group lost during 2020 one of its members, Celso Franco. Another member, Márcia Quaresma, has a precarious professional link to LIP, her contract being payed from the COMPASS project. The small dimension of the group is already a limiting factor in the activities the group develops.

Opportunities

The approval of AMBER is a big opportunity for the LIP group to grow and play a major role in this new CERN experiment. The group has the physics background and the experience needed. AMBER is also attractive for new students that were recently integrated in the group.

Threats

The precarious professional link to LIP of members of the group is a serious threat. The plans for the LIP participation in AMBER are also fully dependent on the funding that will have to be guaranteed.

Partons and QCD

Publications

2 Article(s) in international journal(s)
(with direct contribution from the team)

- *"Contribution of exclusive diffractive processes to the measured azimuthal asymmetries in SIDIS"*, J. Agarwala et al. (COMPASS Coll.), Nucl. Phys. B 956 (2020) 115039
- *"Antiproton over proton and K- over K+ multiplicity ratios at high z in DIS "*, G.D. Alexeev et al. (COMPASS Coll.) , Phys.Lett. B 807 (2020) 135600

Presentations

6 Oral presentations in international conferences

- Márcia Quaresma: *"Measurement of pion induced Drell-Yan at AMBER experiment"*, 2020-02-04, Workshop on Correlations in Partonic and Hadronic Interactions (CHPI-2020), CERN, Geneva, Switzerland
- Márcia Quaresma: *"Drell-Yan measurement at AMBER - Studying the hadrons structure"*, 2020-03-30, 4th Workshop on Perceiving the Emergence of Hadron Mass, CERN-online
- Marcin Stolarski: *"Overview of COMPASS Delta-G results"*, 2020-09-30, Workshop "Gluon content of proton and deuteron with the Spin Physics Detector at the NICA collider", JINR, Dubna - online
- Pietro Faccioli: *"Charmonium polarization in pp collisions"*, 2020-10-01, Workshop "Gluon content of proton and deuteron with the Spin Physics Detector at the NICA collider", JINR, Dubna - online
- Pietro Faccioli: *"J/psi production and polarization in pp collisions"*, 2020-11-17, 17th International Workshop on Hadron Structure and Spectroscopy (IWHSS 2020), Trieste, Italy - and online
- Catarina Quintans: *"COMPASS++/AMBER: Preparing Phase II"*, 2020-11-30, 4th Workshop on Perceiving the Emergence of Hadron Mass (EHM IV), CERN - online

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

- Márcia Quaresma: *"COMPASS and AMBER activities"*, 2020-02-15, Jornadas LIP 2020, LIP-Minho, Braga, Portugal

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

- Rita Silva: *"AMBER Experiment at CERN"*, 2020-02-15, Jornadas LIP, LIP-Minho, Braga, Portugal

3 Oral presentations in advanced training events

- Márcia Quaresma: *"The Nucleon"*, 2020-07-15, Initial Lectures of the LIP Summer Internship Program, LIP - Lisboa, Portugal
- Catarina Corte-Real: *"The hidden charm in the COMPASS experiment at CERN"*, 2020-09-11, Final Workshop of the LIP Internship Program 2020, LIP-Lisboa, Portugal
- Maria Francisca Queiros: *" COMPASS acceptance obtained using Machine Learning Techniques"*, 2020-09-11, Final Workshop of the LIP Internship Program 2020, LIP - Lisboa, Portugal

HADES

Collaboration in the HADES experiment at GSI

Principal Investigator:
Alberto Blanco (15)

1 ***Researcher(s):***
Paulo Fonte (5)

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

2 ***Trainee(s):***
Eduardo Neves, Manuel da Veiga

Total FTE:
0.4

Articles in international journals:	**5** Indirect contribution
National Conferences:	**1** Poster presentation
Collaboration meetings:	**2** Oral presentations

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 Partons and QCD group for the analysis of the data produced by the HADES detector. This synergy has had important results such as the recent 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 a group member. 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 present pandemic situation, the proposed work plan for 2020 was carried out, although with some delays. Two points in particular can be highlighted: the finalization of the full DAQ upgrade (both hardware and software) of the RPC-TOF-W, which will allow to achieve a HADES acquisition rate of more than 200 kHz; and the construction and test (with cosmic rays) of the two modules of RPC-TOF-FD (the beam test, scheduled for mid-2020, was postponed to the beginning of 2021). It is important to mention that this work could not have been done without the Detector Laboratory (DL) and Mechanical Workshop (MW).

The group activities are financially supported by a modest funding in the framework of a MoU signed between HADES and FCT. Any opportunity of funding is pursued. The last attempt at the "Fundo CERN" call, in collaboration with the NUC-RIA and NPStrong groups, was unsuccessful.

Finally, and for the first time in the group's history, two students collaborated in the RPC-TOF-FD construction and test in the framework of the LIP Internship Program. The effort to attract students to the group will continue.

HADES

Overview

Presently, only the hardware-related line of work the

has 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 team in Hades. Responsibility: L. Lopes.

Assessment of the past year: objectives vs. achievements

The group objectives as stated in the last report were:

- No production data taking is planned for 2020 in HADES.
- Finalization of the upgrade of the RPC-TOF-W data acquisition system, both from the hardware and software point of view, and final testing in the engineering run planned for June 2020.
- Construction and testing of the first (possibly second) RPC-TOF-FD module in June 2020 at GSI and subsequent construction of the remaining two/three sectors.
- Integration of the RPC-TOF-FD in the official HADES software.
- Continuation of the tests carried out with Lenav2. Integration of the new electronics in some of the HADES planes/sectors and subsequent test in June 2020. Maintenance of the gas systems of the tracking system.

The data acquisition system of the RPC-TOF-W was fully upgraded in the beginning of 2020. More than 2200 TDC channels (based on the CERN HPTDC chip of the TRB2 family) were exchanged for FPGA-based TDCs of the TRB3 family (a system very similar to the DAQ that will be used in the BrainPET project). With the objective to eliminate the limitation imposed by the old TRB2 and to achieve a HADES acquisition rate of more than 200kHz. The new system, with the consequent necessary modifications in the software, was successfully tested with cosmic rays and in an engineering beam in mid-2020, although it was not possible to test completely as not all of the HADES systems were active.

The construction of the first FD sectors was strongly affected by the lock-down in the first quarter of 2020. For this reason the beam test, scheduled for mid-2020, was cancelled. However, thanks to a tremendous effort of the LIP DL and OM infrastructures, two modules were built and tested with cosmic rays before the end of 2020. The results were as expected, a timing precision better than 100 ps and efficiencies above 90%. The rate capacity in the HADES environment will be tested at GSI in a beam time in February 2021. The integration of the new detector in the official HADES software is not yet finished but it is well advanced.

The pandemic situation severely affected the planned activities related to the collaboration with the MDC group and basically all of them where postponed for 2021.

Although this was not planed, two students joined the group (for a couple of weeks) in the framework of the LIP Summer Internship Programme to help on the construction and test of the RPC-TOF-FD modules. The work was presented as a poster in the 22nd National Physics Conference in September 2020.

Lines of work and objectives for next year

- In beam test of RPC-TOF-W (equipped with new DAQ system) with all HADES systems in operation.
- In 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 frame work of LIP Summer Internship Programme and by proposing Master 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.

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 prospects for the next years is focused in our main three lines:

- Optimize (in particular verify the DAQ upgrade during 2021 beamTime), prepare and operate the RPC-TOF-W.
- Finalize the construction, commissioning and integration of the new RPC-TOF-FD in 2021.

  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.

Weaknesses & threats

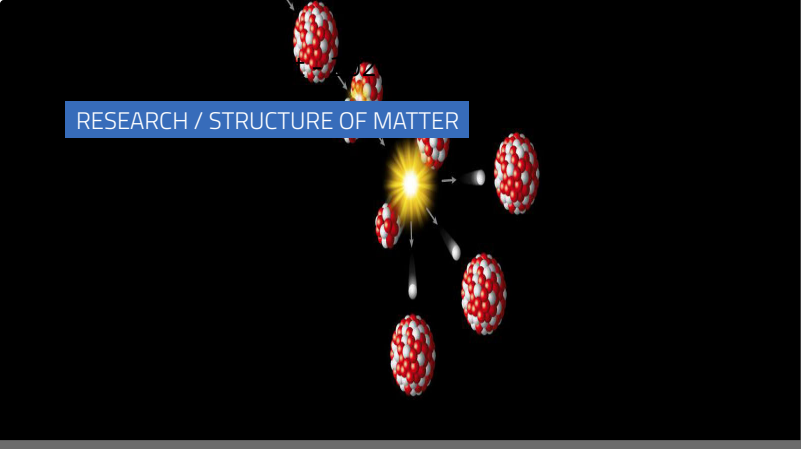
- The reduced number of team members and their commitments with other projects.
- The lack of funding may strongly compromise all the group activities.
- The loss of the data analysis component weakens the group.
- The apparent unattractiveness of HADES physics.

HADES

Presentations

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

- Eduardo Neves: *"Um novo detetor de tempo de voo para a experiência HADES"*, 2020-09-02, FÍSICA 2020 – 22ª Conferência Nacional de Física, Lisboa



NUC-RIA

Experimental Nuclear Astrophysics

Principal Investigator:
Daniel Galaviz (92)

4 ***Researcher(s):***
Jorge Sampaio (*), Luis Peralta (*),
Pamela Teubig (80),
Paulo Velho (100)

1 ***PhD Student(s):***
Elisabet Galiana (100)

3 ***Master Student(s):***
Beatriz Pinheiro Pereira (4), Francisco Barba (100),
Manuel Xarepe (100)

3 ***External collaborator(s):***
Ana Isabel Henriques, Ricardo Pires, Rita Pestana

Total FTE:
5.8

(*) starting in 2021

Articles in international journals: **5** Direct contribution
2 Indirect contribution
Completed theses: **1** Master

Executive summary

It is not possible to start a summary on 2020 without mentioning the pandemic situation the world has gone and is going through. Our group, whose activities ground on collaborative efforts with different groups and at various laboratories in Europe, has seen its activities seriously affected by COVID-19. Part of the research planed for last year could not be performed and was either postponed or cancelled. However, this did not mean a complete stop of the activities of the group, with the execution of locally based fundamental experiments, and preparations for expanding during 2021. The following topics can be highlighted:

- Cancelation of INVERSE-ALPHA experiment at INFN/LNS: The experimental run, led by the group and expected to take place during this year, was scheduled for beam time on the second half of March 2020. Just one week prior to the start of the experiment, the pandemic situation forced the laboratory to close its installations and limit all research activities. The experiment was originally postponed, and later cancelled, as the upgrade works of the laboratory started on time. A re-evaluation of the possibilities of this research line will be done over 2021.
- New research line for Nuclear Astrophysics: The measurement of astrophysically relevant proton reaction cross sections at low energies was done for the first time using the activation technique and characterizing the produced radioactive isotopes by their X-ray emission. As a benchmark experiment we performed at the CTN laboratory irradiations with low-energy protons on natural Sn targets (also done locally at our evaporator facility), determining for the first time the cross section of the reaction ^{118}Sn(p,y)^{119}Sb. This opened a new research line of the group, with possible expansions in the near future.
- RPCs for measuring relativistic protons at R3B: Within the experimental collaboration at FAIR, and in collaboration with the RPC group at LIP Coimbra, we explored the possibility to include an existing large area timing RPC into the experimental setup of the R3B collaboration, to measure the momentum of high-energy protons emitted in reactions studying the characteristics of short-range correlations in nuclei. If the conditions allow, the RPC detector will be brought to GSI during 2021 and will be used in the experimental campaign scheduled for 2022.
- Beta-delayed neutron counter with RPCs: we started the interaction with the LIP Coimbra group to define the characteristics of a RPC-based detector, aimed at measuring the high-energy neutrons emitted after the beta-decay of exotic neutron-rich nuclei. The expected performance of the detector is reasonably high, and the design of a small prototype should start during 2021.

Sources of funding

PI	Code	Amount	Dates	Description
Daniel Galaviz	CERN/FIS-PAR/0005/2017	24.640 €	2018-07-01 / 2020-12-31	PORTUGAL at ISOLDE

Total: 24.640 €

NUC-RIA

Overview

The group's activities can be summarized in 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.

For 2021, following the advances on proton therapy and the expected implementation of a cyclotron in Lisbon, we foresee the opening of a research line on this topic. However, once established, it will be an open discussion if this should remain in this group or join efforts with the LIP Dosimetry group.

Assessment of the past year: objectives vs. achievements

Within the two research lines defined for the group, we had foreseen the following activities for 2020:

- Participation in the R3B 2020 campaign.
- Execution of alpha elastic in inverse kinematics at INFN/LNS in Catania.
- Resubmission of experimental proposal S442 to FAIR-PAC (Proposal Advisory Committee).
- Analysis of PIGE (particle-induced gamma ray emission) data from Chlorine isotopes at CTN.
- Low-energy proton capture on ^{118}Sn for nuclear astrophysics at CTN.
- Contribution to the expected PANIC2020 conference, and to the NUSTAR Week 2020 meeting, both planned to happen in Lisbon.

As previously mentioned, the pandemic had a severe impact on the group activities. Here we provide a more complete list of the achievements (and downs) during 2020.

Starting on the bright side of life, the achievements of the group were:

- Activities at INFN/LNS: During the first two months of the year, the group was quite active at the LNS laboratory in Catania, participating in two periods of beam time devoted to two approved proposals: a test experiment related to the INVERSE-ALPHA proposal, studying the effect of a ^{58}Ni beam at 150 MeV on a thin Silicon target with high amounts of helium trapped in it; and an experiment to study the scattering of ^{10}Be on ^{120}Sn nuclei. The data from both runs will be the topic of the Master Thesis of the student Francisco Barba.
- Proton capture reactions for Nuclear Astrophysics: A new line of research was initiated at the CTN laboratory on the measurement of (p,γ) reaction cross sections at low energies using the activation technique. The novelty resulted in the measurement of the X-ray yields after the decay of the produced radioactive nuclei. This is the first time the technique is used on proton capture reactions. The first case was the study of the reaction ^{118}Sn(p,γ)^{119}Sb. The work and the results were the topic of the Master Thesis of Manuel Xarepe, who defended the work in the beginning of 2021.
- During the second half of the year, in the framework of the R3B collaboration at FAIR and together with the LIP Coimbra RPC group, the group explored the possibility of using a timing RPC as a relativistic proton ToF Wall. The excellent timing properties of the existing RPC in Coimbra (developed for a beam test of the SHiP experiment) would significantly improve the measurement of the momentum of the emitted protons. The R3B collaboration already expressed its will to have the module for the experimental campaign planned for 2022.
- Modeling of an RPC-based neutron counter: in collaboration with the RPC group, we have worked on the modeling of a highly segmented neutron counter, based on ^{10}B-coated RPCs. First results indicate that the technology could be applied to the measurement of high-energy neutrons emitted following the beta decay of very exotic nuclei.
- Simulation and data measurements with photons: The work of the PhD of Elisabet Galiana has advanced through 2020 by completing the analysis of the measured data at the CTN laboratory, both from the PIGE studies on Chlorine isotopes and from natural gamma and cosmic-rays induced background. The data was benchmarked with GEANT4 simulations adapted to the experimental environment. Publications on this topic are expected in 2021.

The year however had several drawbacks, not allowing the execution of the following foreseen goals:

- The experiment INVERSE-ALPHA, scheduled for beam time at the INFN/LNS laboratory, was cancelled due to the pandemic situation in March. No re-scheduling is foreseen at this stage.
- The pandemic also considerably reduced the research activities of the R3B collaboration. As for the group, we were not able to participate on-site at R3B.

Lines of work and objectives for next year

Even if the present year still presents several restrictions caused by the pandemic, the group has a very challenging 12 months ahead, with several topics regarding instrumentation, experiment execution and data analysis. The following presents a list of the lines of work we foresee for the upcoming months:

- Continuation of (p,γ) experiments at CTN: following the successful campaign initiated in 2020, we aim at continuing this line of research with the detailed measurement of the $^{118}Sn(p,\gamma)^{119}Sb$ reaction cross section using the X-ray yields emitted in the decay of the produced products. We will continue as well exploring the nuclear chart, identifying possible cases we can measure in the future with this new technique.
- R3B experiments at FAIR: the experimental program at FAIR still suffers from the restrictions due to the pandemic. Nevertheless, the schedule for the experiments planned for 2021 (March and April) still holds, and we will try to contribute to them on a remote basis, with special focus on the CALIFA calorimeter. Furthermore, the group will explore the possibility to contribute, together with the RPC group, to the R3B setup with an existing tRPC system to detect high energy protons after the GALD dipole magnet. The detector would be brought to Darmstadt during the second half of the year, setting up for experiments scheduled for May 2022. This contribution strongly depends on the availability of funds that the group wants to seek in the national call for projects open beginning of the year. We also foresee the seeking of a PhD grant to work on this topic.
- Analysis of BeSn experiment: The involvement of the group in further analysis of reactions with exotic nuclei will count with the analysis of the experimental data from the reaction $^{10}Be + ^{120}Sn$, measured at the LNS/INFN laboratory in Catania (Italy). The characterization of the effective thickness of thin (20 μm) Single-Sided Silicon Strip Detectors (SSSDs) will be the main topic of work for the Master Student Francisco Barba, who is expected to get involved in further phases of the data analysis.
- Contribution to RPC thermal neutron systems: The group will further contribute to the task related to the development and application of boron-coated RPCs for thermal neutron detection. In addition to further explore the possibilities of these modules from the modeling point of view, the evaporator system the group has in Lisbon will be used to study the properties of thin layers of copper evaporated on glass slides typically used in these detectors, exploring a new approach for the construction of very thin electrodes on these modules.
- Additional Nuclear Astrophysics activities: Complementary to the experimental efforts devoted to the study of reactions with impact on nuclear astrophysics studies, we will start with the Master. in Physics student Afonso Jantarada the implementation of the nuclear reaction network code NucNet-Tools (from Clemson University) to explore the sensitivity of the astrophysical network to the reaction cross sections the group is measuring, allowing as well for the identification of relevant reaction cross sections that need to be measured in the future.
- Meetings in Lisbon: The group will be involved over 2021 in the organization of international meetings that are planned to be held in Lisbon, if the situation allows it. A direct responsibility of the group is the General Assembly of the COST Action ChETEC (Chemical Elements as Tracers for the Evolution of the Cosmos), foreseen for July 2021; and the so-called NUSTAR Week, the yearly meeting of the FAIR pilar NUSTAR (NUclear STructure, Astrophysics and Reactions) outside Darmstadt, foreseen for September 2021. Members of the group will also contribute to the organization of the PANIC conference.

Additional actions to contribute to the outreach activities of LIP are foreseen, like the organization of the IPPOG Masterclasses at FCUL (this year, in online format) and the involvement in the LIP Summer Internship Programme.

Medium-term (3-5 years) prospects

After some years being part of LIP, the group has established its activity around fundamental nuclear reaction physics. Recently, collaborations with other LIP groups namely the Simulation and Big Data Competence Center, instrumentation groups and infrastructures (Neutron Detectors, Dosimetry, LOMaC), and theoretical groups (NPStrong) have started, with promising expansion perspectives.

On a medium term, the group aims at establishing its participation in mainly two laboratories, namely:

- The R3B collaboration at FAIR in the study of nucleon knock-out reactions at relativistic energies.
- The ISOLDE experiment at CERN, with the study of low-energy nuclear reactions with radioactive beams.

The establishment in these collaborations is one of the main goals of the group for the mid-term future.

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 accelerators. Ability to expand the present collaborations to other institutes.

Weaknesses Just one full-time senior member and the lack of funding to attract and retain new members. This lack of funds also affects the possibility to effectively contribute to the construction of new detection systems in the international collaborations in which the group is involved.

Opportunities The establishment of a line of research for fundamental nuclear studies is an unique opportunity the group offers, attracting students at various levels. The know-how of the group offers as well the opportunity to link the instrumentation used in fundamental nuclear research to future applied nuclear physics facilities in Portugal.

Threats The possibility to effectively contribute to the next generation facilities like FAIR is presently real. If the group does not manage to execute such a contribution, future participations in this facility are under threat.

- Francisco Barba: *"Detector characterization in nuclear reaction experiments at LNS (Catania, Italy)"*, (ongoing)

NUC-RIA

Publications

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

- *"Scission configuration of U-239 from yields and kinetic information of fission fragments"*, D. Ramos, M. Caamano, A. Lemasson, et al. , Phys. Rev C 101, 034609 (2020)
- *"Novel solid 4 He targets for experimental studies on nuclear reactions: 6Li + 4He differential cross-section measurement at incident energy of 5.5 MeV"*, F. J. Ferrer, B. Fernandez, J. P. Fernandez-Garcia, et al., Eur. Phys. J. Plus 135, 465 (2020)
- *"Performance recovery of long CsI(Tl) scintillator crystals with APD-based readout"*, P. Cabanelas, D. Gonzalez, H. Alvarez-Pol, et al., Nucl. Instr. and Methods A 965, 163845 (2020)
- *"Tl concentration and its variation in a CsI(Tl) crystal for the CALIFA detector"*, A. Knyazev, J. Park, P. Golubev, et al., Nucl. Instr. and Methods A 975, 164197 (2020)
- *"Probing the Z=6 spin-orbit shell gap with (p,2p) quasi-free scattering reactions"*, I. Syndikus, M. Petri, A.O. Macchiavelli, et al., Phys. Lett. B 809, 135748 (2020)

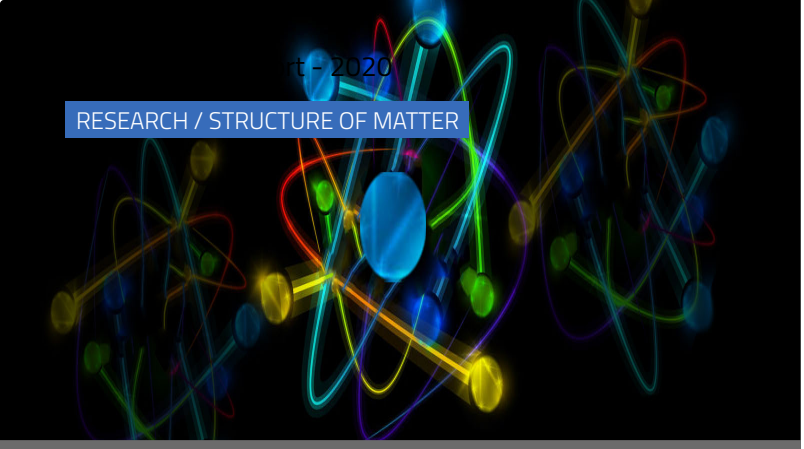
Theses

2 PhD

- Pamela Teubig: *"Advanced simulation and particle reconstruction in the CALIFA calorimeter and data analysis treatment for the R3B experiment at FAIR"*, 2011-06-01, (ongoing)
- Elisabet Galiana: *"Analysis and simulation of (p,g) and PIGE low energy reactions: An ENSARRoot developmen"*, 2018-01-01, (ongoing)

2 Master

- Manuel Xarepe: *"Determination of 11Sn(p,y)11Sb cross section at astrophysical relevant energies from X-ray yields"*, 2021-01-29, (finished)



NPStrong

Nuclear Physics and Strong Interaction Group

Principal Investigator:
Teresa Peña (100)

3 ***Researcher(s):***
Alfred Stadler (100), Elmar Biernat (10), Gernot Eichmann (100)

3 ***Master Student(s):***
André Torcato (16), Eduardo Ferreira (25), Madalena Lourenço (50)

2 ***Trainee(s):***
Heitor Österdahl, Miguel Ralha

1 ***Undergraduated Students:***
Miguel Peixoto

Total FTE:
4

Articles in international journals:	**12** Direct contribution
International conferences:	**1** Oral presentation
International meetings:	**1** Oral presentation
Advanced Training Events:	**1** Oral presentation
Seminars:	**2** Seminars
Completed theses:	**1** Master
Organized Events:	**1**

Executive summary

NPstrong, the Nuclear Physics and Strong Interaction Group, joined LIP in the beginning of 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.

The scientific activities of the group in the year 2020 comprise 12 publications, including three invited reviews, one completed and two ongoing master theses, two student projects within the LIP Internship Program, organizing a three-week INT program "Accessing and Understanding the QCD Spectra", and a planned workshop "Strong Interactions in Lisbon", which had to be cancelled due to the COVID-19 pandemic. The main scientific achievements of the year concerned the topics of heavy-light four-quark states, four-quark vs. quark-antiquark components in the sigma meson, pentaquarks, hyperon electromagnetic form factors, among others, as detailed below.

Sources of funding

PI	Code	Amount	Dates	Description
Gernot Eichmann	RD0713	22.382 €	2017-04-01 / 2021-12-31	Multiquarks

Total: 22.382 €

NPStrong

Overview

The group NPStrong currently consists of four senior members (two of them permanent) and several 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

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).

Assessment of the past year: objectives vs. achievements

The scientific activities of the group in the year 2020 comprise:

- 12 publications, including three invited reviews,
- 1 completed and 2 ongoing master theses,
- 2 student projects within the LIP Internship Program,
- organizing a three-week INT program "Accessing and Understanding the QCD Spectra",
- a planned workshop "Strong Interactions in Lisbon", which had to be cancelled due to the COVID-19 pandemic.

Concerning the composition of NPStrong, being embedded in the LIP Internship Program proved to be beneficial and we could significantly expand our group by attracting new master students. In the following we highlight the main scientific achievements of the year 2020:

Heavy-light four-quark states: We employed Dyson-Schwinger equations (DSEs) and four-quark Bethe-Salpeter equations (BSEs) to discriminate between existing models that describe heavy-light four-quark candidates such as the X(3872). Such models typically assume internal structures in the form of diquark-antidiquark clusters, heavy-light-meson clusters or heavy-light meson molecules. We identified the dominant components for various quantum numbers and suggested experimental candidates. Most notably, we found strong meson-meson and negligible diquark components in all

c-q-cbar-qbar states, whereas for c-c-qbar-qbar states diquarks are also present.

Four-quark vs. quark-antiquark components in the sigma meson: We studied the dynamical generation of the sigma resonance, where we generalized the four-quark BSE to include a mixing between four- and two-quark components. We found that the two-pion contribution is mainly responsible for the low mass of the sigma, whereas quark-antiquark components induce only small effects. We studied the analytic structure of the sigma resonance in the complex momentum plane and found a branch cut at the two-pion threshold and a singularity in the second Riemann sheet, indicating a considerable decay width.

Pentaquarks: We explored the recently discovered LHCb pentaquark states in a coupled-channel BSE approach with hadronic exchanges between mesonic and baryonic constituents. We established a new method to deal with complications that can appear in relativistic bound-state equations, in particular complex conjugate eigenvalues. We included the relevant channels contributing to these pentaquarks (Σc-D, Σc-D*, p-ηc and p-J/ψ) and found the Σc-D and Σc-D* components to be dominant. The master student who performed this work (Madalena Lourenço) successfully completed her studies in January 2021.

Hyperon electromagnetic form factors at large timelike q^2: Information on the internal structure of hyperons is sparse due to their very short lifetimes and currently limited to the magnetic moments of a few hyperons. Revealing their electromagnetic structure through e+e− scattering has become possible only recently at BaBar, BES- III and CLEO and presents a new opportunity to study the role of valence quark effects, diquark clusters and different quark compositions. We used model-independent asymptotic relations between the form factors in the spacelike and the timelike regions, which become exact in the limit $q^2 \to \infty$, to calculate the timelike electric and magnetic form factors of Λ, Σ, Ξ and Ω baryons. Interestingly, we find that the perturbative QCD (pQCD) limit only sets in above $q^2 = 30 - 50$ GeV^2, way above the region where the symmetry relations are valid. This is due to an interplay of two scales: the meson masses that determine the quark electromagnetic current through vector-meson dominance, and the momentum scales determined by the size of the hyperons.

Covariant model for the Dalitz decay of the N(1535) resonance: The electromagnetic structure of the $\gamma^*N \to N(1535)$ transition is non-trivial and suggests an interplay of valence quark and meson cloud effects. Valence-quark models describe the Dirac form factor well, whereas chiral models predict meson cloud contributions to the Pauli form factor at low Q^2. We used experimental data from proton and neutron targets to infer meson-cloud contributions in the spacelike regime, which in contrast to the Δ(1232) and N(1520) reveal an important isospin dependence. Timelike experiments with pion-induced reactions provide an alternative way to probe the physics of neutron targets, and in the future our calculation can be compared with dilepton decay rates measured at HADES.

Light and heavy quark mass functions in Minkowski space: The dressed quark mass function encodes mass generation for hadrons due to dynamical chiral symmetry breaking. Building on previous chiral-limit results in the Covariant Spectator Theory (CST), we calculated the mass function from a one-gluon-exchange interaction for non-zero quark masses and all quark flavors. The free parameters of the problem were fixed to spacelike lattice-QCD data at low quark masses and to the strong coupling at the heavy-flavor scale. Incorporating the quark mass function will help us to achieve a fully consistent, dynamical description of mesons.

Lines of work and objectives for next year

In 2021 we expect to continue our strategy of sustained growth, which includes the need for attracting master and PhD students. We also aim to strengthen our ties to other groups at LIP, in particular those in the Structure of Matter research line and the Pheno group. We aim to continue providing high-impact results with international recognition and maintaining close ties to experimental efforts at the LHC experiments, COMPASS/AMBER, FAIR, Jefferson Lab and the future Electron Ion Collider (EIC). To this end, we will deepen our well-established lines of research but we are currently also exploring new research directions that could considerably expand the portfolio of the group:

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.

Meson spectroscopy: We aim for a comprehensive description of meson properties in the Covariant Spectator Theory by implementing a dynamically obtained quark mass function.

Baryon spectroscopy and structure: We want to understand the spectrum and structure of hyperons, including their spacelike and timelike form factors. We are also investigating the spectrum of heavy baryons, in particular those with different flavours, to shed light on the newly discovered states at LHCb.

Hadrons on the light front: Among our exploratory studies is how to calculate light-front wave functions using contour deformations. If successful, this will allow us to calculate PDFs (parton distribution functions) and TMDs (transverse momentum distributions) using functional methods, thereby also establishing close ties with experimental efforts at the future Electron Ion Collider.

Fundamental properties of QCD: Solving the fundamental DSEs of Yang-Mills theory (i.e., QCD without quarks) can provide a glimpse into the underlying mechanisms of confinement and dynamical mass generation. In the medium/long term this can serve as the starting point for genuine ab-initio calculations for hadron properties.

Machine learning for functional methods: We are beginning to explore ways to utilize machine-learning tools in theoretical hadron physics. The accumulated expertise from other LIP groups can be beneficial in this area.

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, 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 number of master students has significantly increased during last year)

Threats

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

NPStrong

Publications

12 Articles in international journals
(with direct contribution from the team)

- *"Hadron spectroscopy and structure in the Dyson-Schwinger approach"*, G. Eichmann, Springer Proc. Phys. 238 (2020) 783
- *"Masses and Structure of Heavy Quarkonia and Heavy-Light Mesons in a Relativistic Quark Model"*, A. Stadler, S. Leitão, M. T. Peña, E. P. Biernat, Springer Proc. Phys. 238 (2020) 723
- *"Relativity in Few-Hadron Systems: Analysis of Baryon Electromagnetic Transition Form Factors in the Covariant Spectator Theory"*, M. T. Peña, G. Ramalho, Springer Proc. Phys. 238 (2020) 715
- *"Hyperon electromagnetic timelike elastic form factors at large q2"*, G. Ramalho, M. T. Peña, Phys. Rev. D 101 (2020) 1, 014014
- *"Towards Heavy-Light Axialvector Tetraquarks in a Dyson-Schwinger/Bethe-Salpeter approach"*, P. C. Wallbott, G. Eichmann, C. S. Fischer, Acta Phys. Polon. Supp. 13 (2020) 139
- *"Quark mass function from a OGE-type interaction in Minkowski space"*, E. P. Biernat, F. Gross, M. T. Peña, A. Stadler, PoS LC2019 (2020) 028
- *"Covariant model for the Dalitz decay of the N(1535) resonance"*, G. Ramalho, M. T. Peña, Phys. Rev. D 101 (2020) 11, 114008
- *"Sigma-meson: Four-quark versus two-quark components and decay width in a Bethe-Salpeter approach"*, N. Santowsky, G. Eichmann, C. S. Fischer, P. C. Wallbott, R. Williams, Phys. Rev. D 102 (2020) 5, 056014
- *"Disentangling different structures in heavy-light four-quark states"*, P. C. Wallbott, G. Eichmann, C. S. Fischer, Phys. Rev. D 102 (2020) 5, 051501
- *"Four-quark states from functional methods"*, G. Eichmann, C. S. Fischer, W. Heupel, N. Santowsky, P. C. Wallbott, Few Body Syst. 61 (2020) 4, 38
- *"Diquark correlations in hadron physics: Origin, impact and evidence"*, M. Yu. Barabanov, M. A. Bedolla, W. K. Brooks, G. D. Cates, C. Chen, et al. (27 authors), Prog. Part. Nucl. Phys. 116 (2021) 103835
- *"The anomalous magnetic moment of the muon in the Standard Model"*, T. Aoyama, N. Asmussen, M. Benayoun, J. Bijnens, T. Blum et al. (132 authors), Phys. Rept. 887 (2020) 1

Presentations

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

- Elmar Biernat: *"Quark mass function from a OGE-type interaction in Minkowski space"*, 2020-03-31, Perceiving the Emergence of Hadron Mass through AMBER@CERN

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

- Gernot Eichmann: *"Phenomenology of light exotic hadrons with functional methods"*, 2020-09-03, Snowmass 2020 RF7 Meeting, USA,

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

- Gernot Eichmann: *"From quarks and gluons to hadrons"*, 2020-02-05, 5th Lisbon Mini-School on Particle and Astroparticle Physics, Caparica

2 Seminars

- Gernot Eichmann: *"From quarks and gluons to hadrons and nuclei"*, 2020-06-02, Division seminar, Argonne National Laboratory, USA
- Gernot Eichmann: *"From quarks and gluons to hadrons and multiquarks"*, 2020-06-04, LIP Seminar, LIP

Theses

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 , (ongoing)
- André Torcato: *"Heavy-baryon spectroscopy in a quark-diquark approach"*, 2020-11-01 , (ongoing)

[Cosmic rays]

AMS

Auger

SWGO/LATTES

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 ***External collaborator(s):***
Eduardo Bueno, Jiahui Wei, Laurent Derome

Total FTE:
3.3

Articles in international journals:	**2** Indirect contribution
International conferences:	**1** Oral presentation
Collaboration meetings:	**3** Oral presentations

Executive summary

since 1998 LIP is part of the broad international collaboration that designed and operates the Alpha Magnetic Spectrometer (AMS). The project had two distinct phases: first a prototype was built and flown aboard the space shuttle in 1998 and, later, 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 in the RICH detector. 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 CR (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 analyses. 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 sections. 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 establishing 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 FB (Fernando Barão) started supervising Eduardo Bueno, PhD student on their group.

Sources of funding

PI	Code	Amount	Dates	Description
Fernando Barão	CERN/FIS-PAR/0013/2019	50.000 €	2019-09-01 / 2021-08-31	Collaboration in the International Space Station Experiment AMS for the detection of intermediate energy cosmic rays

Total: 50.000 €

AMS

Overview

The main activities where the 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 is used in analyses where accurate velocity measurements are required, such as mass separation in isotopic studies.

2. AMS data variability studies

Solar activity, varying in a periodic way, 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 the 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 BDT (boosted decision trees) or PDF (probability density functions) techniques. Such tools were applied to anti-proton/electron separation and to isotopic identification. Currently, the group's main focus on this topic is deuteron separation with respect to its closest most abundant species, the proton. It requires accurate characterization of the measurements involved, state-of-the-art data analysis techniques and 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) headquartered 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

T1. Monitoring and operation of the RICH detector in the POCC control room at CERN

Up to the end of 2019, members of the group (Fernando Barão and Miguel Orcinha) performed shifts at AMS control centre (POCC) at CERN. The main goal of these shifts was the monitoring of the AMS detector installed on the International Space Station. In addition to the regular shifter tasks, the members of the group are usually also expert-on-call. Due to the COVID-19 outbreak and associated travel restrictions, no more shits were attended by any of AMS' collaborators except for members based at CERN. The group intends on returning to shifts as soon as a solution is available.

T2. Variability studies of proton and electron fluxes at low energy and their interpretation under solar modulation models

The activities related to this topic were done in the context of MO's PhD thesis which is currently being written. This task mostly involves the estimation of the time-variable proton CR flux and its correlation with solar activity.

This flux is calculated using an analysis framework developed by this group and is significantly sped up by using reduced data "ROOT trees" produced by another member of the collaboration (Laurent Derome, researcher at LPSC in Grenoble), in collaboration with this group. Due to disk storage constraints at the LPSC data centre, the group had to reprocess part of the data and store it at CERN's data centre. This effort resulted in extending the flux up to March 2019. Currently, the proton flux is estimated from May 2011 to March 2019.

The selection algorithm for protons is finished and the group is working towards efficiency estimation and regularization in order to accurately portrayal the detector's effect. The group developed an adaptive spline fitting algorithm to regularize the efficiencies.

Currently the group is developing a Bayesian unfolding algorithm (this effort is 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. This is a major improvement on the current algorithm since it allows for the efficiencies to be differently time-binned from the rates in order to deal with low statistics, which may lead to very imprecise efficiency estimations. This unfolding algorithm is to be used on the deuteron flux as well (Task 3).

The group continued working on the correlation of the proton flux with solar parameters and this work is still undergoing as MO finishes his PhD.

T3. Light isotope nuclei identification

In November 2019 LIP and Netherlands - Groningen AMS group joined efforts on deuteron analysis of AMS data as FB started supervising Eduardo Bueno, PhD student on their group.

Selection of deuterons is intrinsically a difficult task given their very low abundance with respect to the major proton component. Essentially, as in any isotopic analysis, the separation of both species can be carried out by selecting particle velocities and looking into the momentum spectrum, naturally separated for different particles masses, once momentum resolution effects allow.
A more "natural" way is to look into the derived mass spectrum. The key issue in isotopes separation is the building of the reference distributions for fitting the full mass spectrum. These mass templates

are built from MC simulations and this requires studying detector resolution and systematic biases of MC samples with respect to data in order to evaluate corrections to be applied to MC.

Another aspect that affects the templates is the spectral shape and the fact that our analysis is only targeting primary events with a rigidity above the geomagnetic cutoff. MC events were re-weighted according to the measured rigidity proton spectral shape and according to their probability of being primary, despite their measured rigidity being higher than the cutoff.

Compared to Time-of-Flight, the RICH detector is able to measure particle velocities with a ten times better resolution.
However, for singly charged particles, there are only a low number of hits near the velocity threshold (specially the 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. Therefore, proton/deuteron selection criteria have to be developed having these aspects in mind. For that purpose, machine learning methods combining different detectors and measurements are being studied.

The group presented these results in several AMS analysis meetings during the course of the year and at an international conference.

Lines of work and objectives for next year

T1. POCC

AMS detector's operation in Space and data quality control implies continuous monitoring (24 hours over 24 hours) from two dedicated NASA centres called Payload Operations and Control Center (POCC) one headquartered at CERN for the day shifts and the other at CSIST (Chung Shan Institute of Science and Technology) for the night control shifts. AMS operations take place from there, including commanding, storage and analysis of house keeping data and partial science data analysis for rapid quality control and feedback.

LIP team members have been participating in the AMS mission control activities, performing shifts and acting as on-call experts for the RICH subdetector. LIP shifters are responsible for monitoring the RICH, TOF and ECAL subdetectors and reporting any anomalies to shift leaders and on-call experts assigned to each specific subdetector.

Due to the COVID-19 pandemic, these activities have been postponed for now.

T2. Variability studies of proton and electron fluxes at low energy and their interpretation under solar modulation models

The group will parametrize relevant observables and connect them to propagation parameters such as diffusion coefficient and magnetic field in order to make a consistent model which can then be tuned to AMS data and validated with other experiments.

Inclusion of complex structures such as the heliospheric current sheet and a latitude varying solar wind speed will be made possible in the more complex 2D framework developed by the group and its collaborators since they are important factors in both high and low activity periods and influence how differently charged particles are transported through the heliosphere.

Solar modulation is a phenomenon of diffusive transport of charged particles through a magnetized turbulent plasma. This diffusion has a dependence on not only particle kinetic energy but also on velocity, making it then dependent on the particle mass-to-charge ratio A/Z. One can use isotope ratios such as $^{1}H/^{2}H$ and $^{3}H/^{4}H$ to study particles with the same charge but different velocities in order to probe the diffusion models or to reconstruct the Local Interstellar Spectrum (LIS) by removing the solar modulation effect from the measured flux. The group expects to study this velocity effect using higher charge nuclei and isotopes.

Solar parameters present complex time structures, which result from the contributions of the several solar phenomena. These include not only periodic events such as the reversal of the magnetic field (about every 11 years), but also solar flares with a changing frequency in time, random turbulent fluctuations and even overall (10 to 100 year) trend shifts.
The group will separate these components by developing a data-driven filtering method based on Empirical Mode Decomposition (EMD) which will be applied to solar, AMS and neutron monitor data in order to extract both long-term trends and short-term solar event induced fluctuations. The variations seen in the flux of CRs can be directly correlated to solar parameters from a few months before.

T3. Light isotope nuclei identification

The deuteron isotopic physics analysis is in progress and the major ongoing issues to be worked out along 2021 will be described hereafter.

Deuteron/proton separation requires the use of mass templates that can be derived directly from Monte Carlo or defined analytically from detector velocity and rigidity responses. However its tiny abundance makes deuteron counting very sensitive to mass tails caused by mis-reconstruction of velocity or rigidity. Therefore these observables are required to accurately describe the data effects. That imposes rejecting those mis-reconstructed events and for the remaining ones working on getting a good agreement between data and MC.

To obtain the deuteron and proton fluxes, efficiencies have to be evaluated from Monte Carlo and corrected with detector efficiencies directly estimated from data (trigger, beta and rigidity reconstructions).

Finally, the flux has to be de-convoluted from experimental detector effects (unfolding) and, for that, a data-driven Bayesian unfolding approach is being developed by the group. It includes detector resolution and possible biases on observables due to

energy losses or other physical effects.

This unfolding technique is of particular importance in time-resolved fluxes since it can be applied repeatedly to time slots of data without requiring the re-weighting of the MC dataset. This study will result in the ratio of deuteron to proton fluxes, in terms of rigidity and kinetic energy per nucleon. In addition, the ratio to ^{3}He and ^{4}He can also be derived since deuterons are a spallation product of helium crossing interstellar matter in the galaxy.

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 modeling, 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 due to the group's experience with both the RICH detector and with data-driven likelihood models applied to particle separation. The topic of isotopic separation 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 constitutes a great opportunity to explore new separation techniques like using the geomagnetic cutoff effect to build mass templates.

SWOT Analysis

Strengths

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

Weaknesses and Threats

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

Presentations

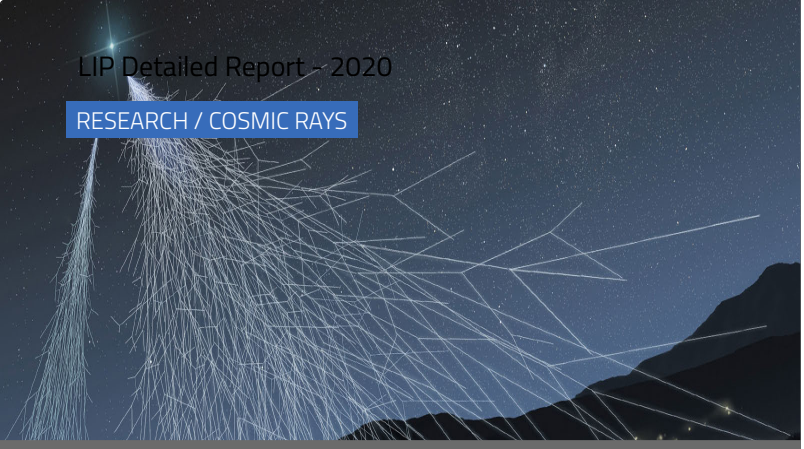
1 Oral presentation(s) in international conference(s)

- Jiahui Wei: *"Measurements of Light Nuclear Isotopic Composition in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station"*, 2020-07-30, ICHEP 2020, 40th International Conference on High Energy Physics, Prague, Czech Republic

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 (80)

14 ***Researcher(s):***
Alessandro de Angelis (15), Bernardo Tomé (65), Catarina Espírito Santo (15), Felix Riehn (100), Gonzalo Parente (50), Helmut Wolters (13), Liliana Apolinário (15), Lorenzo Cazon (100), Mário Pimenta (40), Patrícia Gonçalves (20), Pedro Abreu (80), Raul Sarmento (100), Ruben Conceição (50), Sofia Andringa (20)

4 ***Technician(s):***
José Carlos Nogueira (75), Luís Lopes (30), Luís Mendes (75), Miguel Ferreira (75)

2 ***PhD Student(s):***
Pedro Teixeira (100), Ricardo Luz (50)

2 ***Master Student(s):***
Alexandra Fernandes (28), Miguel Martins (33)

5 ***Trainee(s):***
Henrique Gonçalves, Jorge Gouveia, Luis Amorim, Miguel Pereira, Pedro Passos

1 ***Undergraduated Students:***
Magda Duarte

2 ***External collaborator(s):***
João Espadanal, Mélina Fontes

Total FTE:
12.3

Articles in international journals:	**5** Direct contribution **9** Indirect contribution
Internal notes:	**3** Collaboration notes
International conferences:	**1** Oral presentation
International meetings:	**3** Oral presentations
Collaboration meetings:	**6** Oral presentations
Advanced Training Events:	**3** Oral presentations
Seminars:	**2** Seminars **1** Outreach seminar
Completed theses:	**1** PhD
Events:	**1**

Executive summary

The Pierre Auger Observatory, the largest cosmic ray (CR) detector, has brought new fundamental insights into the origin and nature of highest-energy cosmic rays while raising further questions about their nature, origin, and the physics governing interactions at the highest energies. 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. On the other hand 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 the Earth's atmosphere is not tested by human-made accelerators, resulting in the dominant uncertainty in the description of EAS which thus hampers the comprehension of the whole UHECR picture.

The Pierre Auger Collaboration is performing a full detector upgrade, consisting of installing scintillators on top of the existing water Cherenkov detectors (WCD) and on 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 EAS observables and thus understand their development. 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 WCD. Low flux RPCs developed at Coimbra were built in cooperation with Brazilian institutes, and their first data were 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 for detailed shower studies at lower energies (10^{18} eV).

The LIP team holds great expertise in shower physics. Previous work on model development and innovative analysis methods will allow the team to give a central contribution to the analysis of the new Auger data. Namely, the team is leading ongoing efforts to measure the muon content of showers, and has unveiled the relation with the interactions that occur at early stages of the shower development by analyzing the shower-to-shower muon fluctuations.

Part of the group activities were severely impacted due to the COVID-19 pandemic. The travel restrictions and strict confinement in Argentina made it impossible to complete the detectors' commissioning and substantially impacted fieldwork even by the Observatory staff.

Sources of funding

PI	Code	Amount	Dates	Description
Pedro Assis	CERN/FIS-PAR/0034/2019	135.000 €	2019-09-01 / 2021-08-31	Enhancement of the measurement capabilities of the Pierre Auger Observatory
Lorenzo Cazon	CERN/FIS-PAR/0031/2019	75.000 €	2019-09-01 / 2021-08-31	UHECR Physics with the Pierre Auger Observatory

Total: 210.000 €

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 focused on 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 the muon detection capabilities.

Assessment of the past year: objectives vs. achievements

The year 2020 was heavily affected by the COVID-19 pandemic. Argentina, the site of the Observatory was heavily impacted with strict restrictions for travel and severe lockdowns. Also, Brazil, with whom strong cooperation exists, has suffered a severe impact, namely in Rio de Janeiro. This has had a substantial impact on the development of hardware for the MARTA detector, detector commissioning and activities that require trips to the field.

The most significant impact was 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. We have expected to have the first data in mid-2020. This target is pending until travel to Argentina and fieldwork is possible. Also, the final production of modules in Brazil has suffered a severe impact. However, at Lisbon, we have proceeded with tests on the electronics with mock setups to test and develop hardware and software solutions for deployment at Malargüe.

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.

We had the objective to develop the MARTA software and simulation framework, which was possible to achieve. It is now deployed in the framework of auger simulation and offline analysis. It constitutes an important step and provides a framework for further MARTA studies.

The study of the EAS properties had a significant development. It was possible to finish works on the relation of the very first interactions with the shower structure, namely the muonic component characteristics. These works were presented in several forums and are being published in high impact journals.

The presential outreach activities were impossible to hold as expected. Auger is preparing the public release of its data and, connected to that, the group is developing a strategy to exploit this data and conduct activities with students through masterclasses. The group was able to perform some internships and to plan the scripts of several outreach activities.

The outreach at Mina do Lousal has also been pursued, and a strong 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 and organized in the following tasks:

- Auger detector performance & calibration
- MARTA commissioning and monitoring
- MARTA simulation and data analysis
- Detector & electronics R&D
- Shower & muon reconstruction
- Shower physics & hadronic models
- Implications for mass & global UHECR Interpretation
- Cosmic ray analysis for education and society

During 2020 L. Cazon was the leader of the Shower Physics Task and by the end of the year has been nominated as a science coordinator of the Collaboration. P. Assis is the leader of the Calibration Task. S. Andringa is a member of the Conference Committee.

The main activities will be two-fold in the next year: on the one hand, to commission the MARTA detector; on the other hand, to pursue the studies on the EAS reconstruction with the present and future detection capabilities.

It is possible that in the northern summer, travel restrictions are lifted as the vaccination against COVID reaches a high level. In this case, we will plan missions to Argentina in September. We will then commission the detectors and have the first data from the first array station with a MARTA detector. We will also include the two hodoscopes in this mission and start testing the response of an Auger WCD with enhanced angular precision and azimuthal range.

The implementation of the MARTA software and analysis as a standard tool allows kickstart simulations and analyses with a reduced effort. We plan to develop and propose analyses and

hypotheses to be tested with simulation. The developed analysis can then be applied directly to real field data. We hope to attract students willing to develop their Master or PhD theses.

Work on the understanding the shower development will focus on the relation between first interactions and the shower observables and the possibility to measure them with present and planned detectors. It will be centered on the muon component and the possibility to use the muon footprint on ground to measure first-interaction properties. Attention will also be put on the possibility to improve the measurement by adding information from the other detectors.

In what concerns outreach, we expect to finish the tests of the new detector for Lousal and by the end of the year to have it installed in the field, collecting data. We will also work on an interactive module to be on exhibition at the Lousal mine museum. We also plan to prepare and if conditions allow to hold a masterclass on cosmic rays.

SWOT Analysis

Strengths

The LIP team is relatively large, both in the number of 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 Coimbra RPC team and the Minho analysis team.

The FCT commitment with the Portuguese participation in the Pierre Auger Observatory, valid until 2025, provides a steady framework.

MARTA detectors have proved their capabilities for running in harsh environments showing RPCs are suitable for cosmic ray experiments. Most of the necessary pieces for the deployment of the Engineering Array are produced.

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

Weakness

The team has a rather small number of master and PhD students, leading to a lack of workforce on some of the existing tasks and for 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 and the MARTA project. 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 program in Physics and participating in thematic schools is increasing the awareness on this field. The LIP Remote Control Room at Técnico has also significantly contributed.

R&D opportunities or potential RPC applications in future astroparticle physics projects should be pursued, with a great synergy with LATTES group and muon tomography project.

Threats

The group is attracting too few students for its diversified activities. Lack of funding for PhD students is also a threat to the further development of the group activities.

Auger

Publications

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

- *"Studies on the response of a water-Cherenkov detector of the Pierre Auger Observatory to atmospheric muons using an RPC hodoscope"*, Pierre Auger Collaboration (374 authors), J. Instrum. 15 (2020) P09002
- *"The hadronic interaction model Sibyll 2.3d and extensive air showers"*, Felix Riehn, Ralph Engel, Anatoli Fedynitch, Thomas K. Gaisser, and Todor Stanev, Phys.Rev.D 102 (2020) 6, 063002
- *"The Pierre Auger Observatory and its Upgrade"*, The Pierre Auger Collaboration, Science Reviews - from the end of the world (Argentina) Vol. 1, No. 4, September 2020 // pp. 8-33
- *"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
- *"Direct measurement of the muonic content of extensive air showers between 2x 1017 and 2x 1018 eV at the Pierre Auger Observatory"*, Pierre Auger Collaboration (372 authors), Eur. Phys. J. C 80 (2020) 751

Presentations

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

- Felix Riehn: *"The Pierre Auger Observatory: the universe at ultra-high energies"*, 2020-01-22, 58th International winter meeting on Nuclear Physics, Bormio, Itlay

3 Oral presentations in national or international meetings

- Ricardo Luz: *"Marta: a novel detector at Auger"*, 2020-02-15, Jornadas do LIP, Braga, Portugal
- Felix Riehn: *"News from Auger"*, 2020-02-15, Jornadas do LIP, Braga, Portugal
- Pedro Teixeira: *"Auger: Muon Tomography - LouMu Project"*, 2020-02-15, Jornadas do LIP 2020, Braga, Portugal

3 Oral presentations in advanced training events

- Jorge Gouveia: *"Raios cósmicos num só dia (Cosmic Rays in a single day)"*, 2020-09-10, LIP Summer Internship Program 2020, Portugal
- Luis Amorim: *"Muography of a building"*, 2020-09-10, LIP Summer Internship Program 2020, Portugal
- Gonçalo Gouveia: *"Portable Device based on RPCs for Muons Tomography"*, 2020-09-10, LIP Summer Internship Program 2020, Portugal

2 Seminars

- Ricardo Luz: *"Development of the instrumentation and readout schemes of MARTA, an upgrade of the Pierre Auger Observatory "*, 2020-01-30, LIP Seminars, LIP
- Felix Riehn: *"Ultra-high energy particle interactions at the Pierre Auger Observatory"*, 2020-02-14, , Instituto Galego de Fisica de Altas Enerxias, Santiago de Compostela, A Coruña, Spain

1 Outreach seminar(s)

- Raul Sarmento: *"O Universo e a Física de Partículas"*, 2020-02-28, Masterclasses 2020, Universidade do Minho, Braga, Portugal

Theses

2 PhD

- Ricardo Luz: *"Development of the instrumentation and readout schemes of MARTA, an upgrade to the Pierre Auger Observatory"*, 2015-01-01 / 2020-07-29, (finished)
- Pedro Teixeira: *"Tomografia de Muões com RPCs na Mina do Lousal"*, 2017-09-25 , (ongoing)

2 Master

- Alexandra Fernandes: *"Study of Fast Radio Bursts (FRBs) and multimessenger astrophysics with the Pierre Auger Observatory"*, 2020-09-18 , (ongoing)
- Miguel Martins: *"Measurement of the features of muon number distribution using MARTA engineering array"*, 2020-11-01 , (ongoing)

SWGO/LATTES

R&D for a Gamma Observatory in the Southern Hemisphere

Principal Investigator:
Mário Pimenta (40)

10 ***Researcher(s):***
Alberto Blanco (15), Alessandro de Angelis (15), Bernardo Tomé (35), Catarina Espírito Santo (30), Fernando Barão (15), Giovanni La Mura (100), Paulo Fonte (15), Pedro Abreu (15), Pedro Assis (5), Ruben Conceição (40)

4 ***Technician(s):***
José Carlos Nogueira (10), Luís Lopes (15), Luís Mendes (15), Miguel Ferreira (15)

2 ***PhD Student(s):***
Borja González (*), Ricardo Luz (10)

2 ***Master Student(s):***
Laura Peres (100), Pedro Costa (25)

4 ***Trainee(s):***
António Maschio, Bernardo Martins, Camila Costa, Tomás Ribeiro

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

Total FTE:
5.4

(*) Starting in 2021

Articles in international journals:	**2** Direct contribution
Internal notes:	**2** Collaboration notes
Collaboration meetings:	**21** Oral presentations
Advanced Training Events:	**2** Oral presentations
Seminars:	**4** Outreach seminars
Events:	**1**

Executive summary

The Southern Wide-field Gamma-ray Observatory (SWGO) was formed in 2019 following a workshop in Lisbon. Today, SWGO comprises 52 research institutions from 12 countries. SWGO may cover an extended energy range from the low energy, closing the gap between satellite and ground-based measurements, to very high energy regions, beyond the PeV scale. This extended energy range would provide SWGO with 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, SWGO will be the only wide-field gamma-ray observatory surveying the Southern sky and thus the centre of the galaxy region.

The main goal of the SWGO collaboration is to build the next-generation 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 2022 / beginning of 2023 a complete proposal, including the physics goals, location, observatory layout and detector design, as well as its cost.

The Portuguese participation in SWGO is focused on specific scientific goals spanning many different areas: from the definition of the science requirements to the detector design, from the development of new analysis methods to the design of innovative calibration systems.

In physics, LIP is responsible for the assessment of the SWGO capability for transient sources at low energies (sub-TeV). In 2021, new directions will be explored. The main topics in consideration are galactic Pevatrons, cosmic-ray composition and astrophysical neutrinos.

For the detector design, LIP is proposing a small water Cherenkov detector (WCD) where the light collection is performed by four PMTs placed at the bottom of the tank. This design minimises the amount of water while ensuring good single muon tagging. The possibility of including a smaller PMT to increase the dynamic range, thus enabling the full exploration of the highest energies, will also be studied. The sparse array design will be studied to determine the minimal number of stations needed to ensure good energy and gamma/hadron discrimination capability from 10 TeV to 10 PeV. The group is also pursuing new trigger strategies to lower the experiment energy threshold and a new calibration concept based on a Resistive Plate Chamber (RPC) able to operate at high altitude.

For the simulation and analysis activities, LIP is developing, in collaboration with CBPF (Rio de Janeiro), the University of Granada and the University of Coimbra, analyses to reconstruct the shower energy and core position, as well as machine learning based algorithms to discriminate gamma from hadron-induced showers. The group also has responsibilities for the SWGO simulation framework development.

Sources of funding

PI	Code	Amount	Dates	Description
Mário Pimenta	PTDC/FIS-PAR/29158/2017	239.885 €	2018-05-15 / 2021-05-14	LATTES: an innovative detector for very high energy gamma ray astrophysics in the southern hemisphere
Mário Pimenta	PTDC/FIS-PAR/4300/2020	249.585 €	2021-05-15 / 2024-05-14	SWGO: the wide-field gamma-ray observatory at the Southern hemisphere

Total: 489.470 €

SWGO/LATTES

Overview

The main goal of the SWGO (Southern Wide-field Gamma-ray Observatory) collaboration is to build the next-generation wide field-of-view gamma-ray observatory to be installed in South America. The Collaboration comprises 52 research institutions from 12 countries. The SWGO-LIP group ensures the Portuguese participation in this ambitious project.

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

Assessment of the past year: objectives vs. achievements

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

Task 1 - Detector R&D and site

1.1 RPC prototypes optimisation. The hypobaric chamber built to test the RPCs performance at low pressure was validated up to 500 mbar. An RPC prototype of 0.5 x 0.5 m^2 similar to those of Auger is ready. Two RPCs with 1 x 1 m^2 were produced and are operational to mount an electronic testbench.

1.2 Thermal simulation. The thermal simulation developed in collaboration with the Mechanics Department of IST led to the conclusion that simple correlation for convection inside the tank is not enough to fully describe the physics; the importance of the non-symmetric solar irradiance imposes a 3-D simulation. It was necessary to use Computation Fluid Dynamics (CFD). An implementation in a professional software package (ANSYS Fluent) was started.

1.3 Trigger. A conceptual design for a low energy trigger for SWGO was developed. The trigger strategy is based on a fast pattern recognition of the shower front. An implementation based on an FPGA system is sketched. No show-stopper is found, and energy thresholds below 100 GeV may be comfortably reached at 5000 m altitude with an array of 4 m diameter WCDs covering 80 000 m^2. Two internal collaboration notes were published on this topic.

Task 2 - Simulation and analysis

2.1 WCD design. There are two main layouts presently under study in SWGO: an array of small WCD stations; and detectors deployed in a lake. At LIP, we are currently proposing a design of cylindrical WCD with 4 m diameter and 1.7 m height. The Cherenkov light collection would be done by four photo-sensors placed at the bottom of the tank. As a baseline for the photo-sensors, we are currently using 8 inches PMTs. The rationale of this design is to minimise the amount of water deployed and simultaneously ensure a good single muon tagging. In collaboration with the CBPF group and Auger experts, a rotomolded realistic mechanical design of the tank was done, and its cost was evaluated by a Brazilian firm with considerable experience. The budget negotiated is very encouraging.

2.2 Simulation framework. The collaboration software framework is being developed to perform an adequate comparison between the considered detector concepts. The group participates actively in the coordination of this effort and on the validation of the detector simulation using an independent GEANT4 implementation.

2.3 Gamma/hadron discrimination. Gamma/hadron discrimination is essential since there is a huge cosmic-ray background. Two directions were explored using machine learning techniques: the first in collaboration with the Cognitive and Media Systems group from the University of Coimbra, to identify the primary particle using the shower patterns at the ground; the second with the Computer Architecture and Technology Department of the University of Granada, to identify muons in each station exploiting the four PMTs signal time structure. Both approaches are original and thus were/will be submitted to peer-reviewed journals.

2.4 Shower maximum and energy reconstruction. Innovative methods to reconstruct the slant depth of the maximum of the longitudinal profile (X_{max}) of high-energy showers initiated by gamma-rays, as well as their energy (E_0), were developed. Resolutions of about 40 (20) g/cm^2 and about 30 (20)% for, respectively, X_{max} and E_0 at 1(10) TeV energies were obtained, considering vertical showers. The obtained results are auspicious and can lead to the opening of new physics avenues for large wide field-of-view gamma-ray observatories. The corresponding paper was published.

Task 3 - Phenomenology

3.1 Transient phenomena in SWGO. LIP has a leading role in SWGO driving the efforts to access the so-called sub-TeV gamma-rays, which would cover the energy gap in sensitivity between satellite-bourne and ground-based measurements. We have estimated VHE transients' properties and assessed the detection capability by present and future gamma-ray observatories. This work led to a publication, and a new one is in preparation.

Task 4 - Outreach

4.1 Participation in outreach sessions for the general public and high schools. This activity was undermined by the pandemic situation but still there were a few presential activities in the beginning of 2020 or with appropriate health security measures in place. In these outreach sessions we prepare a table-top cloud chamber - using dry-ice - to visualize the passage of charged particles (originated by the interactions of cosmic rays with the atmosphere), and present and discuss the new concepts associated with Multi-Messenger Astronomy.

4.2 The development and operation of a muon telescope at the Lousal Mine and its exploitation for outreach purposes has been pursued, in collaboration with the Muon Tomography Project (involving the Ciência Viva science centre at Lousal, the University of Évora and LIP), as well as the Auger and ECO groups. A novel detector is being prepared for muon tomography, and an interactive module for the museum is being developed. In 2020 several printed materials were developed, both for distribution to the visitors and to be displayed at the visitor's center and at the detector location (inside the mine gallery).

Lines of work and objectives for next year

2021 is the year in the SWGO R&D program where the possible layouts and detector configuration will be presented and discussed. In collaboration with the CBPF, Padova, and Prague groups, LIP proposed a concept based on small WCD stations with four PMTs at the bottom. The performance of this concept has to be fully established in the entire foreseen energy range of SWGO (100 GeV - 10 PeV). At the highest energies the compact array has to be complemented by a sparse array covering, hopefully, an area of the order of a few square kilometres. An optimised design of the sparse array is one of our goals for 2021. Special attention will be given as well to the gamma/hadron discrimination.

Task 1 - Detector R&D and site

1.1 RPC operation at reduced atmospheric pressure: prototype optimisation and test. RPC prototypes with gaps of several widths will be tested in the hypobaric chamber. The gas system to operate with very low consumption at high altitude will be optimised.

1.2 Improvement of the performance of the thermal simulation. Complete the implementation of the Computation Fluid Dynamics models using the commercial software ANSYS Fluent. Use the ALMA site weather monitoring data to optimise the design of the WCD to cope with the foreseen temperature excursions.

1.3 Trigger of low-energy events. The trigger concept based on the shower front pattern recognition will be finalised and submitted for peer-reviewed publication. The integration of this concept in the full data acquisition system chain of SWGO will be evaluated.

1.4 Site logistic evaluation. One of the LIP members, who has a large experience in the fieldwork at Auger site and dealing with Argentinian and Brazilian companies, became responsible for the logistics evaluation sub-task for the site working group.

Task 2 - Simulation and analysis

2.1 WCD design. The WCD design proposed last year (4 m diameter and 1.7 m height) will be optimised. In particular, the possibility of including a smaller PMT to increase the dynamic range, thus enabling the full exploration of the highest energies, will be studied.

2.2 Array layout design. The sparse array design will be studied to determine the minimal number of stations needed to ensure good energy and gamma/hadron discrimination capability from 10 TeV to 10 PeV.

2.3 Shower reconstruction. An analysis to determine the shower core position using a neural network will be developed in close collaboration with CBPF. Particular attention will be given to showers partially contained in the compact array. The method designed to reconstruct the shower energy at the TeV region will be evaluated at higher energies (> 10 TeV).

2.4 Gamma/hadron discrimination. The two machine learning techniques developed last year (shower pattern and muon tagging) will now be combined to obtain the best possible discrimination in the TeV region. Above tens of TeV, the muon tagging method needs to be redesigned to cope with the sizeable electromagnetic contamination.

2.5 Simulation framework. The effort to build a collaboration software framework will continue to be pursued. Particular focus will be given to reconstruction tools and the creation of instrument response functions. A first end-to-end simulation chain is expected to be completed during 2021.

Task 3 - Phenomenology

3.1 Transient phenomena in SWGO. LIP is responsible for the assessment of SWGO capability for transients at low energies (sub-TeV).

3.2 New avenues. In 2021, new directions will be explored. The main topics in consideration are: galactic Pevatrons, cosmic-ray composition and astrophysical neutrinos.

Task 4 - Outreach

The group has been committed to outreach and dissemination activities in particular with high schools, students and teachers. This engagement will be pursued in 2021, adapting the activities to the pandemic situation while this is necessary. Talks and activities at LIP, in schools and universities, science centres and specific events are planned. The muon tomography demonstrator at the Lousal Mine will continue to be explored to reach the general public (https://pages.lip.pt/loumu (https://pages.lip.pt/loumu)).

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 2022 / beginning 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 PeV. LIP contributes to the design of the detector concept, 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 up to now have been financially supported by a 3-year project FCT/PTDC which ends in May 2021. A new 3-year project was recently approved to start at the end of the current project. This funding will ensure the regular operation of the LIP group during the entire SWGO R&D phase.

SWOT Analysis

Strengths

Expertise 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

Even though the number of students connected to the project has increased in the last year, we still miss Master and PhD students to be able to pursue effectively relevant analyses that can be explored.

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. Large opportunities in many different engineering and physics domains from the design, construction, operation and data analysis.

Threats

It is an ambitious project that will imply considerable financial and human resources. The vision of an open and phased observatory that will cover at the end wide physic goals may be undermined by the concept of a self-contained project with a limited physics goal and budget.

SWGO/LATTES

Publications

2 Article(s) in international journal(s)
(with direct contribution from the team)

- *"Detection of very-high-energy gamma-ray transients with monitoring facilities"*, G La Mura, G Chiaro, R Conceição, A De Angelis, M Pimenta, B Tomé, Monthly Notices of the Royal Astronomical Society, Volume 497, Issue 3, September 2020, Pages 3142–314
- *"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)

2 Internal notes

- *"Conceptual design of a low energy trigger for SWGO"*, P. Assis, R. Conceição, M. Pimenta, B. Tomé, SWGO Internal Note HAP-2020-004
- *"Conceptual design of a distributed DAQ system for SWGO"*, P. Assis, P. Brogueira, R. Conceição, M. Pimenta, B. Tomé, SWGO Internal Note HAP-2020-005

Presentations

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

- Giovanni La Mura: *"Astronomical observations in the visible domain"*, 2020-01-14, Multi-Messenger Astrophysics, 1st International School on Physics of the Universe, 2020, January 14-23, Asiago, Italy
- Pedro Costa e Tomás Ribeiro: *"Development of a next-generation detector concept to detect astrophysical gamma-rays"*, 10-09-20, LIP Internship Program Workshop

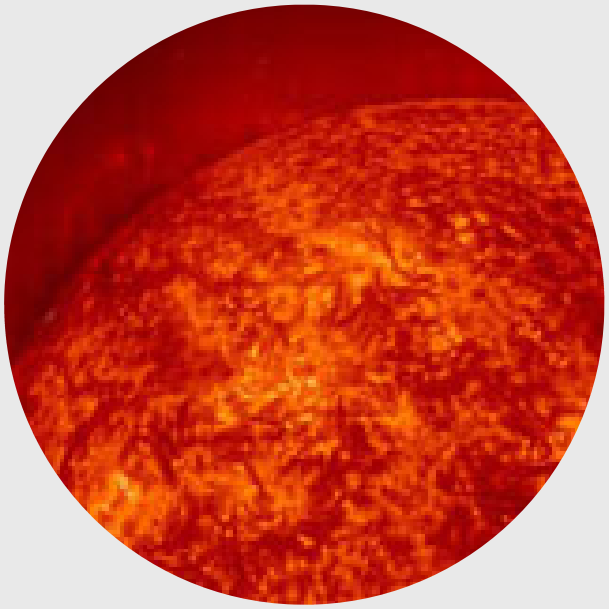
4 Outreach seminars

- Pedro Abreu: *"Hands-on a Cloud Chamber and Multi-Messenger Astronomy"*, 2020-02-10, , Escola Portuguesa de Moçambique, Maputo
- Pedro Abreu: *"Hands-on a Cloud Chamber and Multi-Messenger Astronomy"*, 2020-09-02, FÍSICA 2020 - 22ª Conferência Nacional de Física e 30º Encontro Ibérico para o Ensino da Física, Instituto de Educação da Universidade de Lisboa, Lisboa
- Pedro Abreu: *"Hands-on a Cloud Chamber and Multi-Messenger Astronomy"*, 2020-11-19, , Clube Ciência Viva do Agrupamento de Escolas de Paço de Arcos
- Pedro Abreu: *"Hands-on a Cloud Chamber and Multi-Messenger Astronomy"*, 2020-12-15, , Colégio Militar, Lisboa

Theses

1 Master

- Pedro Costa: *"Detection of astrophysical neutrinos with a gamma-ray observatory"*, 2020-09-14 , (ongoing)



[Dark matter and neutrino]

Dark Matter

Neutrino

SHiP

DARK MATTER

Participation in dark matter experiments: LUX and LZ

Principal Investigator:
Isabel Lopes (65)

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

2 ***Technician(s):***
Américo Pereira (20), Nuno Carolino (35)

2 ***PhD Student(s):***
Guilherme Pereira (100), Paulo Brás (100)

6 ***Master Student(s):***
Andrey Solovov (100), Fátima Alcaso (50), Jacinto Fonseca (58), João Fernando (91), Ricardo Cabrita (100), Susana Castanheira (100)

5 ***Trainee(s):***
Helena Macedo, Inês Sequeira, Pedro Fernandes, Tiago Miguel Martins, Tomas Sousa

Total FTE:
13.6

Articles in international journals:	**5** Direct contribution **6** Indirect contribution
Internal notes:	**9** Collaboration notes
Students notes:	**3**
Proposals:	**1**
International conferences:	**1** Poster
International meetings:	**4** Oral presentations **2** Posters
Collaboration meetings:	**1** Oral presentation
Advanced Training Events:	**5** Oral presentations
Seminars:	**2** Seminars **1** Outreach seminar
Completed theses:	**1** PhD **2** Masters

Executive summary

The LIP Dark Matter group has a long experience in the various aspects of WIMP (Weakly Interacting 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 on WIMP production cross-section 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. LZ is presently completing the assemblage of the last auxiliary systems and mostly engaged in the commissioning of the detector and subsystems. The first science run is expected to start in Autumn 2021, lasting for about 2 months. The group is contributing to several areas of the LZ experiment. We highlight:

- Its leading role in the studies of the LZ sensitivity to the neutrinoless double beta decay (NDBD or $0\nu2\beta$) of ^{136}Xe (the observation of this decay is the second most important physics goal of LZ) and its responsibility on the estimate of the LZ sensitivity to the $2\nu2\beta$ and $0\nu2\beta$ decays of ^{134}Xe, as well as the double electron capture (2EC) of ^{124}Xe.
- Its responsibility for two elements of the experiment infrastructure: the Control System (CS) and the online Data Quality Manager (DQM).
- 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 project is presently about to complete its design phase. The group has responsibilities in the simulations, development of the data acquisition software and user interface, development of the event reconstruction algorithms and background assessment.

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 (Polytetrafluoroethylene) in a liquid interface, including the study of the latter as a function of the temperature. It also comprises the measurement of the PTFE roughness and the simulation of its effect on several aspects relevant for the performance of LZ detector whose walls are made of this material.

Sources of funding

PI	Code	Amount	Dates	Description
Cláudio Silva	IF/00877/2015/CP1311/CT0002	50.000 €	2016-11-01 / 2021-11-30	Optical studies for performance and optimisation of the dark matter experiments LZ and LUZ
Isabel Lopes	PTDC/FIS-PAR/28567/2017	239.807 €	2018-09-01 / 2021-08-31	Participation in dark matter experiments LZ

Total: 289.807 €

Dark Matter

Overview

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 **Online Data Quality Manager system (DQM)** for LZ: this is the on-site system that permits to monitor the detector performance and the data quality in real time (F. Neves, J. Fernando, G. Pereira).
- Modelling, accounting, and GEANT4-based simulation of the radiation **backgrounds** in LZ (A. Lindote, C. Silva, H. Wolters).
- **LZ Control system:** 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 Rutherford Appleton Laboratory (RAL) and involves researchers from Imperial College London (ICL), CERN (Gas Detectors Development Group), LIP, University of Birmingham, University of Oxford, University of Sheffield and University of New Mexico (USA), in a total of about 40 people. The project was approved for funding by the UK's Science and Technology Facilities Council (STFC).

The project aims to observe and to measure for the first time the Migdal effect from nuclear scattering, which allows 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

In 2020, the assemblage and integration of the LZ detector and ancillary systems has suffered a delay of about eight months due to the COVID-19 pandemic, as the access to SURF has been very restricted since March 2020 and there are severe limitations to travelling even inside the USA. Consequently, the commissioning was not completed and the first run has not started yet, contrary to what was foreseen. This change in the LZ schedule impacted our goals that depended on the availability of real data from commissioning and calibration.

Below are listed the main objectives that have been stated for the past year and the critical analysis of what has been achieved.

1 - LZ Analysis Modules (LZap)

Objectives: To tune the pulse classification, pulse finder and pulse matching algorithms using simulation and experimental data. To provide the position reconstruction tool with additional features to improve the definition of the fiducial volume and mitigate the effect of faulty photomultipliers.

Achievements: The goals were achieved with exception of the tuning of the modules with real data because of the LZ delay due to pandemic. The pulse matching, pulse finder and pulse classification modules for LZap were completed and tested with simulated data. The pulse matching and pulse finder modules were also used in the online DQM (see below). In the case of the position reconstruction module, there was also the need to expand its applicability energy range, ensuring its reliability from single electron emission to high-energy gamma calibrations and double beta decay search. A Python interface was also developed for this module, which was not in the objectives.

2 - Online Data Quality Manager (DQM)

Objectives: To install and integrate the DQM, for which the LIP group is responsible. To provide the DQM with all the modules necessary for the detector commissioning.

Achievements: The objectives were all met. Several analysis modules targeting different stages of LZ commissioning were developed, in particular those required for the PMTs tests and the high voltage ramping, including modules for monitoring: i) the health of the photomultipliers from all LZ subsystems; ii) the single photoelectron calibration (SPE) and after-pulses characterization; iii) the performance of the LZ's detector field grids using the PMTs response. Furthermore, a module to assess and tune the DAQ trigger efficiency for both S1 and S2 signals was done. During 2020, we also completed and benchmarked a GPU-accelerated analysis chain. This work was the topic of a master thesis ("Development of the Underground Performance Monitor for LZ").

3 - Physics beyond the dark matter search

Objectives:

3.1 - To use machine-learning algorithms to improve the efficiency in background discrimination and enhance sensitivity in each Xe rare decay that we have investigated.

3.2 Extend to LZ the analysis that led to the determination of the limit of the half-life of the DEC of ^{124}Xe in LUX.

Achievements: The objectives 3.1 were delayed because two of the experts on this topic (A. Lindote and P. Brás) have been involved in the investigation of the sensitivity to NDBD in ^{136}Xe of a larger (3rd generation) xenon TPC for dark matter search, as part of the US Snowmass 2021 process. That resulted in the submission of a Letter of Intent of which A. Lindote is one of the two main authors. It shows that such a detector can be extremely competitive in this field, reaching a world leading sensitivity similar to that of dedicated experiments such as nEXO.

In addition, the group has attained the following achievements:

- The paper on the sensitivity of LZ to neutrinoless double beta decay in ^{136}Xe, of which P. Brás was one of the two corresponding authors, was published. This analysis is also the main physics topic of his PhD thesis, which was submitted in 2020.
- The analysis of LZ to $2\nu2\beta$ and $0\nu2\beta$ decays in ^{134}Xe was updated to account for the 20-fold increase in the maximum expected level of ^{85}Kr in the experiment (this was an unforeseen setback). The analysis was carried out by E. Asamar and resulted in a paper in which he was the corresponding author. It will be submitted soon.
- The paper reporting on the sensitivity of the LUX detector to the double electron capture in ^{124}Xe and ^{126}Xe, of which A. Lindote is the main corresponding author, was published.
- The background model of the LZ detector to the 2EC in ^{124}Xe was developed, and the sensitivity and discovery potential has been estimated, as part of the Masters project of a student whose thesis will be finalised in early 2021.
- A. Lindote is one of the two coordinators of the collaboration workgroup "High energy ER group" (responsible for studying the Xe rare decays) since October 2019 and he will continue in this position until the end of 2021.

4 - Backgrounds

Objectives: To complete the database for LZ backgrounds accounting. To have a preliminary version of the model of the background generated by the decay of daughters of ^{222}Rn plated on the PTFE walls of the detector.

Achievements: The backgrounds database has been finalized. Together with the web interface, a dedicated Application Programming Interface (API) was developed to access and add information in the database directly from analysis scripts. A Python wrapper was developed as a unified interface with the database. The LUX data on the background generated by radionuclides plated on the inner surfaces of the detector was studied. This data is currently used as a proxy for the wall background model of the LZ detector.

5 - Control System (CS)

Objectives: To complete the CS based on Ignition and integrate it with the other components of the experiment infrastructure.

Achievements: We have completed the implementation, based on Ignition, of the slow control of LZ experiment for the detector and the complete subsystems. We implemented interfaces with online experiment infrastructure, most importantly Run Control, DAQ and DQM systems. The Ignition graphic user interface (GUI) was used as a primary user interface for control and for monitoring xenon circulation, purification and storage systems during circulation tests, the major system readiness test before the detector deployment. We provided continuous support for the underground operations throughout 2020. V. Solovov continued as one of the two coordinators of the LZ control system.

6 - Optical studies of reflecting surfaces

Objectives: To measure and characterize the roughness profile of the internal surfaces of LZ, to measure the luminescence of the PTFE used in LZ and the effect of a liquid interface in the reflectance.

Achievements: The roughness profile of the PTFE used in the internal surfaces of LZ was measured using an atomic force microscope. Related to the LZ experiment, we improved the reflectance model for the high-voltage grids, and the PTFE reflectors. A set-up dedicated to the measurement of optical properties for xenon/argon scintillation detectors was assembled, namely the measurement of: i) the PTFE fluorescence for the xenon scintillation light and, ii) the reflectance in a liquid interface to study the effect of the liquid interface in the diffuse reflectance of the PTFE. The required simulations and the test measurements have been made. The pandemic hampered the experimental work foreseen for last year.

Lines of work and objectives for next year

I. Participation in LZ

Our lines of work and objectives for 2021 are in line with what has been our participation in LZ and the schedule of the experiment. In summary, and organized by topic of research, they are:

1. LZap

- Tuning/improvements of the pulse finder and the pulse classifier

to deal with real data acquired during the detector commissioning and calibrations.

- Continue the development of a new method to correct the pile-up of photons in the Photo Counter Module.
- Continue expanding the area of application of the position reconstruction module, namely:
  - to improve the energy resolution and ER rejection efficiency through position-dependent S1 and S2 corrections;
  - to improve the energy resolution for high-energy events by correctly reconstructing the energy for the events that saturate PMTs;
  - to reconstruct the topology of the multiple scatter events for double beta decay search;
  - to reject 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.

2 . DQM

- Implementation of the analysis modules for the various stages of detector commissioning, calibration and operation.
- Upgrade the DQM to use an SQL database to store and retrieve the analysis output objects.
- Maintenance and assistance to the DQM infrastructure.

3 . ^{136}Xe NDBD

- Detailed study of the sensitivity of a 3rd generation xenon detector to NDBD, and publication of a White Paper in the context of the Snowmass 2021 process.
- Assess and develop algorithms to optimise the multiple scattering discrimination capability of LZ in the vertical (z) axis using simulated data, and test the algorithms with data from the first science run.
- Assess the flux of γ-rays produced by natural radioactivity in the rock walls using data acquired with the "Outer Detector" and "skin" systems during the first science run of LZ.
- Adapt the Profile Likelihood Ratio (PLR) framework used for the WIMP sensitivity paper to the ^{136}Xe NDBD search. As a preliminary step, use simulated data to test the modifications.

4. Other Xe rare events

^{124}Xe 2EC:

- Estimate the amount of ^{125}Xe produced by the neutron calibrations during the initial calibration stage of LZ. Use it to estimate the expected amount of ^{125}I and compare it with the observed amount, developing a temporal model for ^{125}I in the detector.
- Use the energy peak from the decay of ^{125}I (67 keV) to determine the energy resolution of the detector in the energy region of the ^{124}Xe DEC (KK channel).
- Compare the background spectrum and observed ^{124}Xe DEC (KK channel) signal in the first run of LZ with the predictions from the models. Reassess the exposure required to reach a 5-sigma discovery, as well as the 3-sigma detection threshold for the KL channel.

$2\nu2\beta$ and $0\nu2\beta$ in ^{134}Xe:

- Use data from the LZ first run to validate and adjust the background model. Reassess the sensitivity projections and estimate the required exposure to reach world-leading limits.

5. Backgrounds

- Finalise the interface module between the backgrounds database and the background analysis framework, making the required adjustments for fitting the background model to the data acquired in the first run of LZ.
- In a similar approach to what was done for LUX, 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. Control System

- Integration of the experiment subsystems that were delayed (source injection, water tank, sampling system).
- Support during the detector cool-down, liquid xenon fill, recovery tests and calibration runs.
- Reorganize the access control to the experiment subsystems, reflecting the transition of the experiment from construction to operations.
- Upgrade the alarm and notification system in order to better support regular detector operations with online and offline shifts.

II. Participation in Migdal Project

In this project we are responsible for the simulations of the backgrounds in the ISIS facilities where the experiment will be carried out, design of part of the set up (collimators and shielding), development of the data acquisition software of the experiment and the associated user interface, development of the event reconstruction algorithms and study of the background from random coincidences.

III. R&D on optical properties of PTFE

The main set of measurements of the PTFE fluorescence and the liquid reflectance in a liquid interface will be carried out and the results published. Furthermore, we will start to plan:

i) the measurement of the reflectance of the PTFE for the xenon scintillation light as function of the temperature; ii) the study VUV-induced degradation of the PTFE reflectance.

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, using a PLR analysis. In the later case, we plan to use not only the classical PLR but also to explore machine learning algorithms specialized in pattern recognition to increase the discrimination of the (0ν2ß) signal against background. 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 of ^{124}Xe.

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

3 - We will be strongly involved in the plans towards the construction of a third generation WIMP search experiment or/and the upgrade of LZ detector. Those plans are not clear yet and they are strongly dependent of how LZ and XENONnT perform.

The group will continue its commitments regarding the CS and DQM maintenance, as well as the participation in the operation activities regarding LZ. We will remain responsible for any assistance or 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 and their physics aspects. 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, as it happened last year with the Migdal Project. The group has a laboratory in Coimbra to operate liquid xenon detectors.

Weaknesses

We have only two PhD students (one of them will defend his thesis in March).

Opportunities

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

Threats

Presently, the most important threat is the pandemic, namely the difficulties and consequent delays it can impose to LZ commissioning and starting of first science run.

Dark Matter

Publications

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

- *"Simulations of events for the LUX-ZEPLIN (LZ) dark matter experiment"*, D. S. Akerib et al., Astroparticle Phys.125, 102480
- *"The LUX-ZEPLIN (LZ) experiment"*, D. S. Akerib et al. (381 authors), Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 953 (2020) 163047
- *"Projected WIMP sensitivity of the LUX-ZEPLIN dark matter experiment"*, LUX-ZEPLIN Collaboration (178 authors), Phys. Rev. D 101 (2020) 052002
- *"Projected sensitivity of the LUX-ZEPLIN experiment to the 0 nu beta beta decay of Xe-136"*, LUX-ZEPLIN LZ Collaboration (192 authors), Phys. Rev. C 102 (2020) 014602
- *"Search for two neutrino double electron capture of 124Xe and 126Xe in the full exposure of the LUX detector"*, D.S. Akerib et al., J. Phys. G: Nucl. Part. Phys. 47 105105

1 Proposal(s)

- *"A 3rd generation liquid xenon TPC dark matter experiment sensitivity to neutrino properties: magnetic moment and 0νββ decay of 136Xe"*, A. Lindote, I. Olcina et al.,, Letter of Interest submitted to Snowmass2021

8 Internal notes

- *"Background Model Generator Tool in MDC3"*, Scott Kravitz, Amy Cottle, Alex Lindote, Ibles Olcina, Quentin Riffard, AnalysisDocDB000033
- *"LZap Single Scatter Selection in MDC3 "*, P. Brás, F. Neves, S. Shaw, K. Stifter, LZ Analysis note - AnalysisDocDB000035
- *"Noise Monitoring Analysis"*, F. Neves, Internal LZ Note
- *"PMT Monitoring Analysis"*, F. Neves, Internal LZ Note
- *"LED Calibration Analysis"*, F. Neves, Internal LZ Note
- *"After-Pulse Monitoring Analysis"*, F. Neves, Internal LZ Note
- *"Pulse Classification Monitoring Analysis"*, F. Neves, Internal LZ Note
- *"HV Grids Monitoring Analysis"*, F. Neves, Internal LZ Note

1 Collaboration note(s) with internal referee

- *"PMT-OFF taskforce report "*, Asher Kaboth, Jordan Palmer, Theresa Fruth, Chris Nedlik, Vladimir Solovov

Presentations

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

- Cláudio Silva: *"Sensitivity of the LUX-ZEPLIN experiment to the 0νββ decay of Xe-136"*, 2020-06-23, XXIX International Conference on Neutrino Physics and Astrophysics, Online Conference

4 Oral presentations in national or international meetings

- Paulo Brás: *"Machine Learning tools for pulse classification in LZap"*, 2020-02-13, 2a reunião do projecto BigDataHEP , Braga
- Andrey Solovov: *": Neutrinoless double beta decay classification in the LUX-Zeplin TPC "*, 2020-02-13, 2a reunião do projecto BigDataHEP , Braga
- Ricardo Cabrita: *"LUX-ZEPLIN overview and status"*, 2020-02-14, Jornadas do LIP 2020, Braga
- Paulo Brás: *"Search for rare xenon decays and study of the Migdall effect in LZ "*, 2020-02-14, Jornadas do LIP 2020, Braga

2 Poster presentations in national or international meetings

- Guilherme Pereira: *"The nervous system of the LUX-ZEPLIN detector"*, 2020-02-12, Research Day at Department of Physics, University of Coimbra, Coimbra
- Guilherme Pereira: *"The nervous system of the LUX-ZEPLIN detector"*, 2020-02-14, Jornadas do LIP 2020, Braga

5 Oral presentations in advanced training events

- Alexandre Lindote: *"Materials and geometry"*, 2020-02-11, LIP Introductory Course on GEANT4, Braga
- Alexandre Lindote: *"Optional (but very useful) Classes"*, 2020-02-12, 1st LIP Introductory Course on GEANT4, Braga
- Guilherme Pereira: *"The nervous system of the LUX-ZEPLIN detector"*, 2020-02-14, 6th IDPASC/LIP PhD Students Workshop, Online
- Elias Asamar: *"Introduction to dark matter"*, 2020-07-01, Estágios da Universidade de Coimbra/Departamento de Física, Coimbra
- Elias Asamar: *"Introduction to dark matter and neutrinos"*, 2020-07-16, Estágios do LIP, Online

2 Seminars

- Alexandre Lindote: *"Dark Matter: from the galaxies to deep mines"*, 2020-02-20, Encontro Nacional de Estudantes de Física 2020, Coimbra
- Elias Asamar: *"Search for WIMPs and sub-GeV dark matter particles using double-phase xenon detectors"*, 2020-11-05, Seminário do LIP, Online

1 Outreach seminar(s)

- Alexandre Lindote: *"LIP: das partículas à saúde"*, 2020-12-04, Ação de Divulgação do Núcleo de Estudantes do Departamento de Física

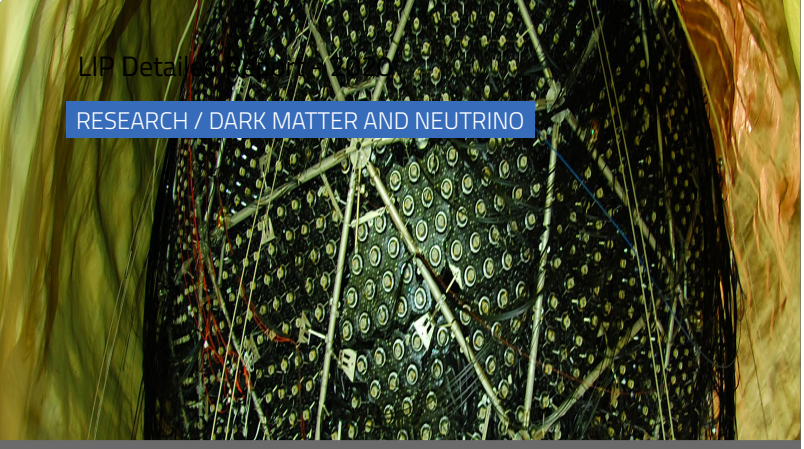
Theses

2 PhD

- Paulo Brás: *"New physics phenomenology and data processing tools for the LZ experiment"*, 2016-01-01 / 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)

6 Master

- Jacinto Fonseca: *"Detection of Magnetic Inelastic Dark Matter"*, 2017-10-02 / 2020-07-31, (finished)
- João Fernando: *"Development of the Online Data Quality Monitor for LZ"*, 2019-09-09 / 2020-11-27, (finished)
- Andrey Solovov: *"Development of analysis techniques for the identification of 0v2ß event topologies and their characterisation"*, 2017-09-01, (ongoing)
- Ricardo Cabrita: *"Efeito do um Interface Líquido na Reflexão de Superfícies Difusoras"*, 2019-09-15, (ongoing)
- Susana Castanheira: *"Discovery potential of the LZ detector to the double electron capture decay of Xe124"*, 2019-09-24, (ongoing)
- Fátima Alcaso: *"Design and optimisation of a xenon TPC with SiPM readout for neutrinoless double beta decay studies"*, 2019-09-15, (ongoing)



NEUTRINO

Neutrino Physics

Principal Investigator:
José Maneira (100)

7 ***Researcher(s):***
Amélia Maio (15), Fernando Barão (25), Francisco Neves (15), Nuno Barros (100), Sofia Andringa (80), Valentina Lozza (80), Vladimir Solovov (25)

3 ***PhD Student(s):***
Ana Sofia Inácio (100), Matthew Cox (100), Stefan Nae (25)

3 ***Trainee(s):***
Diogo Miguez, João Novo, Maria Francisca Góis

Total FTE:
6.7

Articles in international journals:	**6** Direct contribution **5** Indirect contribution
International conferences:	**1** Oral presentation **1** Proceeding
International meetings:	**4** Oral presentations
Collaboration meetings:	**24** Oral presentations

Executive summary

The LIP Neutrino Physics 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 neutrino-less 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 analysis of the data from water and partial fill phases, with leadership or strong contributions to physics analyses (backgrounds and antineutrino studies) and calibrations. The scintillator fill will be completed in mid-2021, with Tellurium loading expected later next year.

In 2018, we joined the DUNE collaboration, with the goal of participating in the leading neutrino physics experiment of the next decade. Our activities are focusing initially on design 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 in 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	Code	Amount	Dates	Description
Valentina Lozza	IF/00248 /2015/CP1311 /CT0001	50.000 €	2017-01-01 / 2021-12-31	Expl. 2015_VL - IF/00248/2015/CP1311/CT0001
José Maneira	CERN/FIS-PAR/0012/2019	130.000 €	2019-09-01 / 2021-08-31	Underground Neutrino Physics: Participation in the DUNE and SNO+ experiments

Total: 180.000 €

Neutrino

Overview

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.
  - Design and fabrication of low energy gamma sources for the scintillator phase.
  - Coordination of the analysis of the backgrounds in the partial fill phase; coordination of studies for the scintillator (+Te) phase, analysis of water phase.
- Analysis of physics data
  - Antineutrinos: preparation of analysis tools aimed at coincidence events typical of the inverse beta decay reaction, including neutron source calibrations.
  - 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 and computing, including design of a dedicated electronics board.
- ProtoDUNE@CERN commissioning and analysis
  - ProtoDUNE Single Phase (SP) DAQ trigger electronics.
  - ProtoDUNE Double Phase (DP) installation, commissioning and purity monitor analysis.
  - ProtoDUNE data analysis: cosmics and beam data, neutron response.

List of internal SNO+ leadership responsibilities: Partial Fill phase (VL) and Water phase (NB) Analysis Coordinators, Anti-neutrino Physics Group (SA), Backgrounds Working Group (VL), Calibration Source Review Committee (JM), Optical Calibration Working Group (JM, NB). JM is also a member of the SNO+ Executive Commiittee and Analysis Coordination Committee. In addition, we are responsible for software documentation, within the software validation group (ASI) and the data processing group (MC).

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

NB is also the coordinator of the HeP neutrino search in the combined 3-phase dataset of SNO.

Assessment of the past year: objectives vs. achievements

SNO+

In terms of the water phase SNO+ data analysis, we achieved all goals we had planned for 2020:

- We used the water phase neutron calibration data to perform and publish a measurement of the neutron-proton capture cross section in water.
- With a new optical calibration, completed by our group in early 2020, the detector response in energy is now understood to better than 1%.
- Those developments, coupled with a background reduction due to better shielding, will improve the precision in a number of ongoing physics analyses – nucleon decay search, solar neutrinos, and well as the anti-neutrino search – where our group participates strongly in coordination and background estimation.

As for the filling operations, the replacement of water in the central volume of SNO+ with liquid scintillator proceeded in 2020 and is nearly complete, despite delays caused by Covid-19. This allowed our achieving several of the goals that required good quality stable data:

- During this fill phase, we led the task of monitoring the radiopurity properties of the scintillator in order to provide feedback to the operations and prioritize future physics analyses.
- Moreover, prioritization of stable radiopurity conditions leads the collaboration to delay internal source calibrations (one of our 2020 goals) until after the first Te-loaded data. We will therefore turn our focus to calibrations with external sources.
- In terms of ^{7}Be solar neutrino analysis, we concluded that the current level of backgrounds is too high to carry that measurement, and so we are pursuing a Boron-8 solar neutrino measurement.
- We working on reactor antineutrino analyses with the partially filled detector data, namely the estimation of the crucial (alpha, n) background.
- We are carrying out preparatory work for the Te-loaded double-beta decay phase, improving rejection techniques for backgrounds in the DBD signal region and studying the residual backgrounds in the DBD region-of-interest.
- We are also developing a semi-analytical detector modeling tool aiming at providing numerical estimations of energy and space location for liquid scintillator detectors, relying on the charge and time signals.

DUNE

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

- We have continued to develop the design of the ionization laser calibration system for the DUNE far detector, that has been published in the Technical Design Report, and had two successful internal reviews this year.
- We contribute both to opto-mechanical systems and to electronics for the interface with DAQ (based upon the board of the already mentioned ProtoDUNE trigger system).
- In 2020 we developed most of the detailed CAD modeling, procured components and produced prototypes of some parts of the system at the LIP workshop. We are in close collaboration with other institutes (mainly Los Alamos and Univ. of Pennsylvania in the US), in view of the final production and installation in ProtoDUNE at CERN in late 2021.
- In 2019 we participated in an experiment (ARTIE) at Los Alamos to measure the neutron elastic cross-section in liquid argon in a poorly known energy region. In 2020 we contributed to the data analysis and a publication is expected soon. This activity is integrated in the design of a calibration system based on an external neutron generator, that had a preliminary test at CERN in ProtoDUNE in 2020.

The first run of the ProtoDUNE prototypes at CERN was concluded in 2020. We participated in the analysis of the ProtoDUNE dual-phase (DP) purity monitor data and in the maintenance of the ProtoDUNE single-phase (SP) trigger system, including the introduction of new triggers used in test runs with a neutron calibration source The analysis of cosmic muon data and search for neutron signals in the ProtoDUNE data was a 2020 goal that we did not meet due, essentially, to the high demands of all the other tasks. Integration of new students in the DUNE activities could help to strengthen this activity.

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). A group member from SNO+ (VL) was invited as an external reviewer for the DUNE backgrounds.

Other activities beyond SNO+ and DUNE

The group was active in the Snowmass process for prioritization of future US Particle Physics projects and has contributed to three proposals. 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);
- Previous work in the GERDA experiment led to a publication on liquid argon detectors;
- Feasibility studies for a next-generation neutrino physics experiment, Theia, where VL co-leads the double beta decay group.

Lines of work and objectives for next year

SNO+

In 2021, after the scintillator fill and the subsequent operations of water removal and PPO addition, a period of background counting will follow, and Tellurium-loading operations are planned for 2022. 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 that data, both for the operational decisions leading to the DBD phase, but also with the goal of producing physics results, namely in reactor and solar neutrinos.

The specific planned activities are the following.

Calibrations and Background

- Finalize the writing and submission of a paper on the optical calibration of SNO+ in the water phase.
- Continue to monitor purity, optical quality (light yield, quenching) of the scintillator during filling. 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

- Coordinate the remaining analyses of the water dataset, and collaborate in the preparation of the corresponding publications, namely papers on antineutrinos, backgrounds (focusing on alpha,n predictions and external background measurements) and nucleon decay.

Scintillator Phase Analysis

- Continue the analysis of the stable 365t period (half-detector) to obtain measurements of Boron-8 solar neutrinos and reactor antineutrinos. There is currently a significant tension between the solar and KamLAND (reactor) neutrino oscillation analysis and the SNO+ reactor analysis, with a different baseline than KamLAND, is crucial to shed light on the issue. A measurement of the solar Boron-8 spectrum in SNO+ can provide more information on the less-known mid-energy range of the spectrum.
- These analyses will require preparatory work to:
    - understand the (alpha,n) reactions as the primary background for the antineutrino study, including the leaching mechanism and the (alpha,n) cross section.
    - develop rejection techniques and classifiers.

- Continue the preparatory work for the double-beta decay (DBD) phase with sensitivities study as a function of cocktail purity, mitigation strategies, and optics effects.
- Continue to expand our scientific links, by being involved with the Snowmass community; reconnecting with the Madrid group for a White Paper on (alpha,n) reactions; restart connections for a DBD workshop in Lisbon.

DUNE

ProtoDUNE

The schedule of ProtoDUNE was affected by the pandemic. In 2021, the main activities will be the decommissioning of ProtoDUNE-1, where we do not plan to participate. Our focus is on the preparation of the calibration hardware for ProtoDUNE-2 (see next point), and its installation is planned for the start of 2022.

We are preparing a common analysis framework for the physics and calibration data of ProtoDUNE, that will be used for those tests.

We are planning a common analysis framework for the physics and calibration data of ProtoDUNE, we'll start from the online data: charge collected per wire as a function of time, using only the basic data cleaning tools. Higher order reconstruction algorithms will be incorporated as our analyses proceed, but the basic framework should allow fast analysis and first view of data as collected.

Calibrations

We will continue to contribute to the design, construction and tests of the ionisation laser calibration system. The main aspects of the mechanical and optical design were done and reviewed in 2020, but several details are remaining and will proceed in 2021. The electronics and instrumentation control software work will also be a priority.

- Measurement of the relative reflectivity at liquid nitrogen temperature of the chosen dielectric mirrors for the laser beam location system (proposed by LIP). Once this is completed, the remaining mirrors will be procured and its supports manufactured.
- Design of the electrical insulation system and of the laser safety coverage of the dual rotary system (proposed by LIP). The work on these aspects will involve a significant contribution from the LIP Mechanical Workshop and Detectors Lab, both in the CAD design and in the construction and test of prototypes.
- Participation in the prototype test campaign, jointly with Los Alamos (LANL), that will send over to Coimbra a rotary stage for He leak checking tests, and for the development of the motorized movement control software. This will lead to the development of software implementing the automatic procedures to perform the complete scan of the active volume, interfaced with the Run Control and DAQ.
- Implementation of our proposal for an electronics interface board with an FPGA and a CPU, to translate DAQ commands to the calibration system, and populating the slow control database with relevant monitoring quantities.

With respect to the neutron calibration work, we will finalize the analysis of data from ARTIE (see Achievements section), and a publication is expected soon. A first test beam with neutrons in ProtoDUNE took place in 2020, and we will focus on the analysis of that data.

In addition, we will continue with an activity to model the space charge effect on electric field uniformity in ProtoDUNE and DUNE, following on work started in 2019 with an Master thesis.

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, and Te-loaded scintillator from 2022 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 experience 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

Three 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. This is a common situation at LIP, and our group is engaging with coordinated efforts to attract students at the undergrad and Masters level.

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.

Opportunities

The shift of SNO+ towards data-taking and physics analysis provides excellent opportunities for Master theses, potentially attracting new students. With the start of the scintillator phase, new topics are explored.

The new 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 2 years. Despite not receiving funding, another project, to cover the SNO+ Te phase, was very well classified in the 2020 general project's call. We plan to resubmit it.

Neutrino

Publications

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

- *"Theia: An advanced optical neutrino detector"*, M. Askins et al (incl. V. Lozza, N. Barros, J. Maneira), Eur. Phys. J. C (2020) 80:416
- *"Measurement of neutron-proton capture in the SNO+ water phase"*, M. Anderson et al. (SNO+ Collaboration), Phys. Rev. C 102, 014002
- *"Deep Underground Neutrino Experiment (DUNE) Far Detector Technical Design Report. Volume I. Introduction to DUNE."*, DUNE Collaboration, Journal of Instrumentation, Volume 15, August 2020
- *"Deep Underground Neutrino Experiment (DUNE) Far Detector Technical Design Report. Volume III. DUNE far detector technical coordination"*, DUNE Collaboration, Journal of Instrumentation, Volume 15, August 2020
- *"Deep Underground Neutrino Experiment (DUNE) Far Detector Technical Design Report. Volume IV. The DUNE far detector single-phase technology"*, DUNE Collaboration, Journal of Instrumentation, Volume 15, August 2020
- *"A search for hep solar neutrinos and the diffuse supernova neutrino background using all three phases of the Sudbury Neutrino Observatory"*, B. Aharmim et al. (SNO Collaboration), Phys. Rev. D 102, 062006

1 International Conference Proceedings

- *"Backgrounds Analysis for the SNO+ Experiment"*, V. Lozza for the SNO+ Collaboration, Proceedings of TAUP 2019, to be published in Journal of Physics: Conference Series

Presentations

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

- José Maneira: *"Techniques for TPC calibration: application to liquid and dual-phase Ar-TPCs"*, 2020-10-08, Topical Workshop on New Horizons in Time Projection Chambers, Santiago de Compostela, Spain (and online)

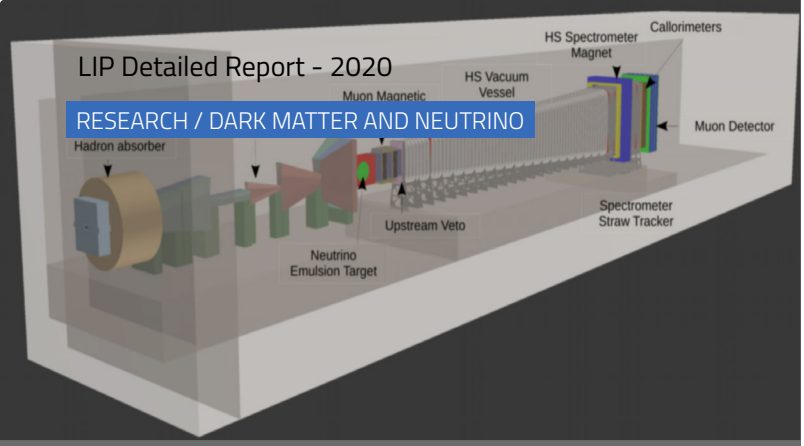
4 Oral presentations in national or international meetings

- Ana Sofia Inácio: *"Measurement of Te130 Two-Neutrino Double Beta Decay Half-life with the SNO+ Experiment: Analysis during the Partial Fill"*, 2020-06-26, 6th IDPASC/LIP PhD Students Workshop, Virual
- Matthew Cox: *"Background Characterisation for Water and Scintillator Phases of SNO+"*, 2020-06-26, 6th IDPASC/LIP PhD Students Workshop, Virtual
- José Maneira: *"Neutrinos: a window into the future"*, 2020-09-28, Workshop on Particle Physics for the future of Europe, Lisbon
- Sofia Andringa: *"Hardware calibration systems for Low Energy at DUNE"*, 2020-12-03, LEP LAr - Workshop on Low Energy Physics for Liquid Argon, online

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)



SHIP

Search for Hidden Particles

Principal Investigator:
Nuno Leonardo (20)

4 ***Researcher(s):***
Alberto Blanco (10), Celso Franco (32), Paula Bordalo (30), Sérgio Ramos (30)

2 ***Technician(s):***
João Saraiva (25), Luís Lopes (5)

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

2 ***Undergraduated Students:***
Beatriz Araújo, Mariana Pinto

2 ***Trainee(s):***
Francisco Safara, Raúl Santos

Total FTE:
2.5

Articles in international journals:	**2** Direct contribution **4** Indirect contribution
Students notes:	**1**
Proposals:	**2**
International conferences:	**1** Oral presentation
Collaboration meetings:	**3** Oral presentations
Completed theses:	**1** Master

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). Currently existing results lead to the realisation that the range of mass scales of new physics may be wide, up to the multi-TeV scales probed at the energy frontier and above, and down to mass scales comparable to familiar matter of GeV and below. Experimental endeavours exploring lower energy ranges therefore complement the LHC in the overarching search effort for new physics. The SHiP experiment at CERN is being designed to search for FIPs that are relatively light and long-lived.

SHiP will constitute 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 further encompasses a SM precision component, involving heavy flavour and neutrino physics, specially allowing for a unique study of the tau neutrino.

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. It is formed of hidden sector and neutrino detector components. Presently SHiP is a CERN recognised collaboration of over 300 physicists from 55 institutes and 18 countries. A prototype of SHiP's neutrino detector (SND) is planned to be installed at the LHC. The new experiment, SND@LHC, aims at taking data already at the upcoming Run 3 of the LHC.

The LIP group is involved in both analysis and detector development. The focus has been placed on the development of timing and veto systems, in hardware and software, towards the goal of achieving maximal efficiency for FIPs with highest purity. The group is directly involved in selection optimization employing machine learning (ML) for several hidden sector particles, including dark photons, heavy sterile neutrinos, and light supersymmetric particles. The group contributes detector development, being responsible for the veto detector (VD) and proponent of a competitive timing detector (TD), based on the resistive plate chamber (RPC) technology.

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, including through internships. A first Master thesis is being concluded.

The search for feebly interacting particles provides a vibrant experimental endeavour in the pursuit of new physics beyond the standard model (BSM) over the coming years in which the LIP group aims at being fully engaged.

SHiP

Overview

The main goal of the SHiP experiment [1] is to search for FIPs [2], exploring the hidden sector of particle physics, in a region of phase space that is largely unexplored and inaccessible to the LHC experiments.

In the context of the recent european strategy process (ESPPU), the physics potential of the experiment was highlighted. While appearing as a frontrunner within the physics beyond colliders (PBC) study, difficulties to financially resource the SPS beam dump facility (BDF) readily were anticipated. Currently, this deliberation effectively resulted in a delay of the TDR phase (Technical Design Review, that had been previously scheduled to start this year) and data taking (previously scheduled for 2028). At the same time, CERN's medium-term plan (MTP) that implements the ESPPU foresees a significant increase (3x) in the PBC allocated budget, that explicitly includes the BDF feasibility studies. A current focus is accordingly being placed in the exploration of aspects associated with the symbiosis between facility and experiment, BDF/SHiP (where one effectively assumes the other).

While the SHiP experiment is a longer-term project, nominally proposed to operate at the SPS accelerator in beam-dump mode, the deployment of smaller, shorter-term, associated projects to address the same physics of interest are being actively investigated. These explore complementary locations at CERN, served with different beam energies and intensities, including at PS, SPS, and LHC. In particular, following favourable feedback by the LHC Experiments Committee (LHCC), the technical proposal for SND@LHC has been submitted, with start of operations foreseen for Run 3 of the LHC next year.

The LIP group carries out activities in both detector development and physics analysis, and is further exploring new opportunities in both fronts in the context of these novel associated projects.

Due to the uncertainty created about the SHiP approval timeline, the projects submitted for funding for the period 2020-21, Fundo CERN and PTDC, were rejected. The group is currently working without funding.

[1] SHiP: The SHiP physics case, CERN-SPSC-2015-017, S. Alekhin et al, arXiv:1506.04855 (2015)

[2] FIPs: The search for feebly interacting particles, G. Lanfranchi et al, arXiv:2011.02157 (2020)

Assessment of the past year: objectives vs. achievements

The line of work of the LIP group in SHiP is subdivided in two main tasks: (1) prototyping of timing and veto RPC detectors, and (2) physics studies and selection optimization using ML.

Task (1) is hardware oriented, involves the development of detectors and associated mechanical structures, module gas recirculation/purification systems, integration of front-end boards. It is carried out by the Coimbra members of the group: Alberto Blanco, Luis Lopes, João Saraiva. The simulation and optimisation of the properties of the timing and veto detectors are also pursued. Task (2) involves simulation of FIPs and conceivable background processes, and development of ML algorithms. This task is performed by the Lisbon members of the team: Paula Bordalo, Celso Franco, Nuno Leonardo, Sérgio Ramos, Guilherme Soares and undergraduate students Francisco Safara, Raúl Santos, Beatriz Araújo, Mariana Pinto. Part of this work is the subject of a master thesis developed in 2020.

The group is directly involved in the optimization of the selection of several hidden particles at SHiP: heavy neutral leptons (HNLs), the hypothetical right-handed neutrinos; dark photons (DPs), coupling to SM via kinetic mixing; axion-like particles (ALPs); neutralinos and sgoldstinos, in low-energy supersymmetry (SUSY). The HNLs provide a natural explanation for the neutrino masses, can account for the observed baryonic asymmetry of our Universe and provide a good dark matter candidate. Concerning the DPs, SHiP can directly detect both their SM and dark matter decays. Regarding the ALP, which is an ideal inflaton candidate, the detection of its double photon decay would mean that SHiP would be recreating the reheating phase of the early Universe. As for the sgoldstinos, SHiP has the potential to probe the SUSY breaking scale up to 105 GeV by detecting their SM decays. The neutralino is the LSP in favoured SUSY scenarios and a dark matter candidate, being probed via R-parity violating signatures.

The group has pursued the development of machine learning algorithms with the purpose of maximizing the selection efficiency for FIPs compared to baseline cut-based analyses. By combining in a multidimensional way the kinematic features of signal and background events together with timing information, provided by the RPC detectors, one expects to maximize the FIP selection efficiency with a nearly 100% purity. Since SHiP is a discovery experiment, this work is extremely important to enable the accumulation of rare events that will allow the observation of BSM signals and the reconstruction of their masses.

Simulated samples of (semi)leptonic decays of HNLs and DPs, along with SM neutrino DIS interactions, were produced employing the FairShip framework. The FIP signals were generated exploring multiple production mechanisms and sets of benchmark values for couplings and masses on the boundaries of expected sensitivity. A set of discriminating kinematic and topological properties was formed, and a baseline set of cut-based selection criteria was implemented. ML algorithms based on deep neural networks were in turn developed, leading to notable improvements in performance.

Selection studies were further extended by exploring additional final states and FIP signals. The DP analysis was enhanced through the generation and study of hadronic final states. Neutralino signals were also generated, again at the boundary of the expected reach in their mass-coupling space, and investigated. Further improvements in

performance were here achieved, exploring neural networks with feature pre-processing, feature probability regression, and classification.

The possibility of relaxing the vacuum level in the decay vessel (DV) was investigated. This was done having in mind the ensuing reduction in cost and for probing analysis feasibility with early data potentially prior to finalized-detector deployment. The preliminary study was performed starting with a DV filled with air at atmospheric pressure. Not unexpectedly, drastic losses in sensitivity were obtained in such extreme conditions relative to standard vacuum conditions.

The group started a close collaboration with the SHiP neutrino group to evaluate the impact of incorporating a VD following the spectrometer of the neutrino detector. An optimisation of the VD was performed and a VD implementation was incorporated in the software framework of the experiment.

Concerning hardware development, several tasks that had been initially planned for this year could not be carried out. These included: (i) building and testing of full-sized RPC modules of the VD; (ii) testing of SAMPIC readout boards; (iii) furthering of mechanical implementation for module placement of the TD. This was due to combined circumstances: delay of the SHiP TDR phase, lack of funding, and the pandemic situation (with ensuing limitations on laboratory based work).

Lines of work and objectives for next year

The line of work of the group stems from the two complementary core activities:

- detector development, with focus on RPC technologies;
- physics studies, with focus on ML methods.

In addition to advancing underlying work on detector prototyping and performance studies in the context of the preparation of the SHiP experiment, the group plans to explore opportunities in both of the abovementioned fronts also in the context of complementary projects that are associated with SHiP and have an earlier expected implementation.

We will continue to support in particular the development of the veto detector and time-based RPC. This follows the baseline tasks the group is contributing to the SHiP collaboration that were listed in the previous report. Importantly, the group will support any necessary developments for the exploration of the BDF/SHiP symbiosis, which will likely become best defined in the coming months.

The task of FIP selection optimization will similarly be further pursued. Including the simulation of additional FIP states and decays, exploring a multidimensional ensemble of benchmark masses and couplings, along with conceivable backgrounds. The identification of associated discriminating features, based on kinematic, topological and timing information, and their exploration in advanced multivariate algorithms. For vetoing and mitigating against background processes originated from SM neutrinos and muons, and to further distinguish and classify amongst potential BSM signals. Further explore the effect of varying vacuum levels on background contamination and sensitivity.

The group intends to expand the collaboration in the neutrino area, that had been initiated in the context of the veto detector and of the tau neutrino analyses, both in the framework of SHiP (SND) and of the new standalone project (SND@LHC). Objectives within the newly formed SND@LHC collaboration, that LIP integrates, are under discussion and will be better defined in the coming months. These range from providing support for construction and operations, preparation for analysis with early data collected in Run 3, to building hardware for an upcoming upgrade.

Medium-term (3-5 years) prospects

The group has the ambition of playing a consolidated role in the search for feebly interacting particles through the active participation in dedicated experimental facilities, and doing so by contributing to both detector development and physics analysis.

In the longer term, the general-purpose SHiP experiment is expected to facilitate a most comprehensive program in this global endeavour. The group has established areas of contribution within the collaboration, around the development of timing and veto systems. While recently several hardware developments have been temporarily delayed or effectively put on hold in view of the delay introduced in the TDR phase, as the timeline becomes duly defined we expect to timely advance with building and testing optimised prototypes of both (VD and TD) detectors.

Baseline sensitivity studies have been recently released by the collaboration for a variety of hidden-sector particles; these are typically based on general assumptions for background rejection. The relevance of detailed studies of background estimation and rejection and accounting of realistic experimental conditions becomes increasingly more central. The group is accordingly well positioned for contributing to such upcoming studies of the experiment's discovery reach and to the preparation and implementation of data analyses.

In the medium term, participation in associated standalone projects with earlier implementation will provide opportunities for advancing with data taking and analysis as well as detector operations. This shall facilitate early physics results with competitive sensitivities, and at the same time address challenges in preparation for later commissioning and operation of SHiP. Among several proposals being currently actively advanced, two reveal to be of particular interest: SND@LHC and SHADOWS@SPS. (The acronyms stand respectively for scattering and neutrino detector at the LHC, and search for hidden and dark objects with SPS.) The first is based on a prototype of the SND sub-detector of SHiP, to be housed in the TI18 LHC tunnel, while the latter aims at placing a hidden-sector spectrometer in the ECN3 SPS

experimental cavern, both at CERN. Both experiments plan to operate in an off-axis setting.

The SND@LHC experiment in particular has already received favourable feedback from the LHCC and a Technical Proposed has been submitted by the collaboration. The experiment is expected to provide first measurements of collider neutrinos and search for FIPs in an unexplored domain. The LHC will deliver the highest energies yet of man-made neutrinos, and their detection will be a milestone. SND@LHC will study all three neutrino flavours in an unexplored energy domain (from 350 GeV to several TeV). The detector will be off-axis with respect to the interaction point (IP1) and, given the pseudo-rapidity range accessible, the corresponding neutrinos will mostly come from charm decays. The proposed experiment will thus probe heavy flavour production in a pseudo-rapidity range that is not accessible to the current LHC detectors.

These projects while currently undergoing active study offer exciting possibilities that will be natural for the group to continue to explore and engage in. Developments expected over the coming months shall allow for a delineated plan of activity for the longer term.

SWOT Analysis

Strengths

- Team 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;
- Project demonstrates ability of consistently attracting students; recent master thesis very successfully accomplished.

Weaknesses

- The project is currently running on a zero budget -- impacting ability to timely deliver several tasks and to retain core students trained in group and involved in physics analysis;
- Departure of one senior team member to industry.

Opportunities

- Long term: if approved SHiP will be a major player in experimental particle physics;
- Medium term: SHiP associated projects with early implementation (e.g. SND@LHC) provide opportunities for early data taking, detector operation and development;
- Physics case currently drawing an explosion of interest, potential to bring significant breakthrough to the field.

Threats

- SHiP is a CERN-recognized project but with approval timeline currently unclear;
- BDF financial resourcing in CERN budget not established, though explicitly included in CERN MTP (2021-25) allocation for PBC which has increased substantially (trebled).

SHiP

Publications

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

- *"The SHiP timing detector based on MRPC"*, A. Blanco, F. Clemencio, P. Fonte, C. Franco, N. Leonardo, L. Lopes, C. Loureiro, J. Saraiva and G. Soares , JINST 15 C10017 (2020)

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

- *"Sensitivity of the SHiP experiment to dark photons decaying to a pair of charged particles"*, SHiP Collaboration, arXiv:2011.05115

2 Proposals

- *"SND@LHC"*, SHiP Collaboration, arXiv:2002.08722
- *"Scattering and Neutrino Detector at the LHC"*, SND Collaboration, CERN-LHCC-2020-013

Presentations

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

- Alberto Blanco: *"The SHiP timing detector based on MRPC "*, 2020-02-10, XV workshop on Resistive Plate Chamber and Related Detectors, 10-14 February 2020, Roma

Theses

1 Master

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

Development of new instruments and methods

[Detector development for particle and nuclear physics]

RPC R&D

Neutron Detectors

Gaseous Detectors R&D

Liquid Xenon R&D

RPC R&D

Resistive Plate Chambers (RPC)

Principal Investigator:
Alberto Blanco (28)

7 ***Researcher(s):***
Andrey Morozov (20), Daniel Galaviz (8), Luís Margato (30), Miguel Couceiro (10), Paulo Crespo (25), Paulo Fonte (43), Susete Fetal (10)

7 ***Technician(s):***
Américo Pereira (15), João Saraiva (45), Luís Lopes (18), Nuno Carolino (10), Nuno Filipe Silva Dias (25), Orlando Cunha (9), Rui Alves (9)

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

1 ***Trainee(s):***
Diogo Gonçalves

Total FTE:
4

Articles in international journals: **3** Direct contribution

International conferences: **3** Oral presentations

Executive summary

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 were, are and will be present in many HEP 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 the work presently 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 RPCs physical modelling and other fundamental issues, such as gas mixture properties and ageing.

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 SHiP experiments/groups, development of **PS-RPCs** cosmic ray telescopes, STRATOS (for Hidronav company) and TRISTAN, both dedicated to the precise measurement of cosmic ray flow, and MUTOM (together with the AUGER group) for muon tomography in mines and finally development of **autonomous** RPCS operated at high altitude (LATTES/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.

During 2020, a new project has been funded (still in the bureaucratic phase). This is AIDAinnova (Advancement and Innovation for Detectors and Accelerators), extension of the previous AIDA project, aimed at participating in the WP7 Gaseous Detectors and specifically for the development of MRPCs for fast timing at high incident flux of charged particles.

Sources of funding

PI	Code	Amount	Dates	Description
Alberto Blanco	STRATOS R&D	20.000 €	2019-01-01 / 2020-12-31	STRATOS R&D
Alberto Blanco	STRATOS	80.000 €	2019-01-01 / 2020-12-31	STRATOS project
Paulo Fonte	POCI-01-0247-FEDER-039808	120.000 €	2019-06-17 / 2021-10-16	HiRezBrainPET: high resolution positron emission tomography (PET) neurofunctional brain imaging
Alberto Blanco	CERN-FIS-INS-0009-2019	70.000 €	2020-07-01 / 2022-06-30	RPCADVANCE : Advancement of the RPC detector technology targeting CERN experiments and applications for society

Total: 290.000 €

RPC R&D

Overview

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

1) The **RPC-PET** technology already applied successfully 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 (by using the time of flight technique) in high energy physics experiments when implementation in large areas is needed. In combination with time, the precise simultaneously measurement of the particle position (**Position Sensitive PS-tRPCs**) is of major interest, since the identification of particles (which relies on timing and position measurements) can be done with a single detector technology without the need to use specific detectors for each task. A direct application of this technology can be found in muon tomography. The spatial resolution achievable (sub-millimetre) and the inherent good adaptation to large areas makes this technology very attractive. Both 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 these 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 as stated in the last report.

- HiRezBrainPET head #0 will be produced and tested, incorporating the lessons thus derived in the system design. We hope to produce the final four heads towards the end of the year.
- Construction and testing of the first (possibly second) RPC-TOF-FD module at GSI and subsequent construction of the remaining two/three sectors.
- Continue supporting the TRISTAN operation and the data analysis (the latter depends on the time left by other activities with higher priority within the group).
- Finalize the integration of MUTOM and initiate the field operation.
- Finalize the R&D of the RPC for high altitude operation.
- Test extensively the sealed RPC technology.
- Initiate the R&D proposed in the RPCADVANCE project.

Due to an error, the objectives for the STRATOS project were missing in last year's report:

- Construction of the first STRATOS prototype module and construction of the remaining seven by the end of the year.

Achievements

The **HiRezBrainPET** head #0 was produced and tested in very realistic conditions (including new, higher density front-end electronics and final detectors), validating the mechanical and electronic designs. A preliminary PET image resolution of 0.97 mm FWHM was measured, in line with the requirements. The knowledge thus gained will be incorporated in the system design. On the other hand the final DAQ system able to deliver 900 MB/s has been setup in close collaboration with HADES-GSI group. The final production of the scanner is now scheduled for Spring 2021.

The construction and testing (with cosmic rays) of the first two **RPC-TOF-FD** sectors for the **HADES** group were completed before the end of the year. Due to delays caused by the pandemic situation, the beam test at GSI and the construction of the remaining sectors was postponed to 2021, as described in the HADES group report.

The operation of **TRISTAN** at the Antarctic base was guaranteed during 2020 and results on the cosmic ray flux measurement capability of the device, showing a precise and stable measurement (< 1%), were presented at the RPC2020 workshop and published in JINST by one member of the team.

During 2020, 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 (although a small sealed box for the DAQ components is still missing) and indoor data acquisition started. Ten months of data acquisition were completed with almost flawless operation of the detector. However, some problems (under investigation) were detected in the DAQ (loss of events and different sensitivity of the channels) although a preliminary muography of the building was possible. MUTOM is a joint activity with the Auger group (more information in the Auger group report).

MARTA type RPCs were tested at pressures from 1000 mB to 400 mB (equivalent to an altitude from see level to more than 6000 m), for the **LATTES/SWGO** project, showing that the conceptual design is valid for this pressure range. The detection efficiency was not measured, which remains an open issue, with possible gap number/width adjustment needed to compensate for any efficiency losses.

Two **sealed RPC** chamber 0.5*0.5 m² operated during 8 months without any indication of malfunctions or performance degradation, pointing to the feasibility of the concept. The results were presented in the RPC2020 workshop, with a very good acceptance by the community, and were published in JINST by a member of the team.

The **RPCADVANCE** project started in mid-2020. Two of the project tasks (sealed RPCs and position-sensitive RPCs) have a strong overlap with other projects in the group and are in a good state of development. Other two tasks, the development of high-count-rate tRPCs and the high-efficiency thermal neutron detector, are somewhat behind schedule and are expected to be strongly developed in early 2021.

The **STRATOS** project has been strongly influenced by the pandemic situation. However the first fully instrumented module was completed at the end of 2020. The gap stack of this detector is enclosed in a new material (polypropylene) which makes it much more resistant to the entrance of moisture and other atmospheric gases. Thus we are currently able to operate the detector at a lower flux (at the moment ~1 cc/min/m²), with the hope of lowering it further. The detector also combines a reasonable spatial resolution (~10 mm, 2D) and a good temporal resolution (300 ps) and efficiency (> 98%) on 2 m².

Although it was not planed, three students joined the group (for a couple of weeks) in the framework of the LIP summer internships program to help on the construction and test of the MUTOM telescope. The work was presented as a poster in the 22nd National Conference of Physics in September 2020.

Lines of work and objectives for next year

- Production and evaluation of 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 due to the pandemic situation the polar campaign has been strongly reduced) and the data analysis now in collaboration with our colleagues at University of Santiago.
- 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 operated in a pressure range from 1000 to 400 mBar with different number/gap-width for the **LATTES/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 (1*1 m²) telescope will be produced 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).

Medium-term (3-5 years) prospects

As a 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, i**n the short-term, the new RPC-TOF-FD for the HADES experiment will be completed and put into operation. The existing R&D line for the SHiP experiment is in this moment in stand by due to the recent developments. On the other hand, the STRATOS detector will be finished in the short-term and the continuation of the collaboration with the Hidronav company, with the aim of designing and building a macro scanner for scanning of cargo containers in ports, will be pursued in the medium-term. We will continue learning with the TRISTAN operation and 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, will be fundamental to advance in this matter and others included in the project, such as the development of simultaneous measurement of position and time or the development of high rate RPCs.

Finally, the group wants to attract students (something that has not been very common in the past) trying to benefit from the recent opening of the Portugal-CERN PhD grants Programme, although the first attempts were not successful.

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.
- Enjoy the confidence of some RPC-enthusiastic colleagues that help to overcome the reduced number of elements of our core team, presenting our work abroad and collaborating with us.

Weaknesses

- The rather small size of the team and their dispersion among many projects (incorporation of students might help).
- The lack of base funding makes the group to be dispersed among different projects.

Opportunities

- We believe to have or being about to have very competitive detectors for the application "markets": animal and human RPC-PET, muon tomography, cosmic ray physics and HEP.
- The human full body RPC-PET application requires a longer and more demanding development, along with much larger funding, but it is potentially hugely interesting.
- The incorporation of P. Fonte full time, which will boost the RPC-PET line.
- The new obtained funding in "Fundo CERN" call will boost the fundamental R&D.

Threats

- Hostile funding environment.
- In the long term, the excessive maturation of the team members will become a determinant factor, students could contribute to mitigate this.

RPC R&D

Publications

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

- *"The SHiP timing detector based on MRPC"*, A. Blanco, F. Clemencio, P. Fonte, C. Franco, N. Leonardo, L. Lopes, C. Loureiro, J. Saraiva and G. Soares , JINST 15 C10017 (2020)
- *"The TRISTAN detector—2018–2019 latitude survey of cosmic rays"*, J.P. Saraiva, A. Blanco, J.A. Garzón, D. Garcìa-Castro, L. Lopes and V. Villasante-Marcos, JINST 15 C09024
- *"Towards sealed Resistive Plate Chambers"*, L. Lopes, P. Assis, A. Blanco, P. Fonte, M. Pimenta, J. Instrum. 15 (2020) C11009

Presentations

3 Oral presentations in international conferences

- Alberto Blanco: *"The SHiP timing detector based on MRPC "*, 2020-02-10, XV workshop on Resistive Plate Chamber and Related Detectors, 10-14 February 2020, Roma
- João Saraiva: *"The TRISTAN detector - 2018-2019 latitudinal survey of cosmic rays "*, 2020-02-10, RPC2020 Workshop, Roma
- Luís Lopes: *"New advances in very low gas consumption"*, 2020-02-13, RPC2020 Workshop , Roma, 12-14, February

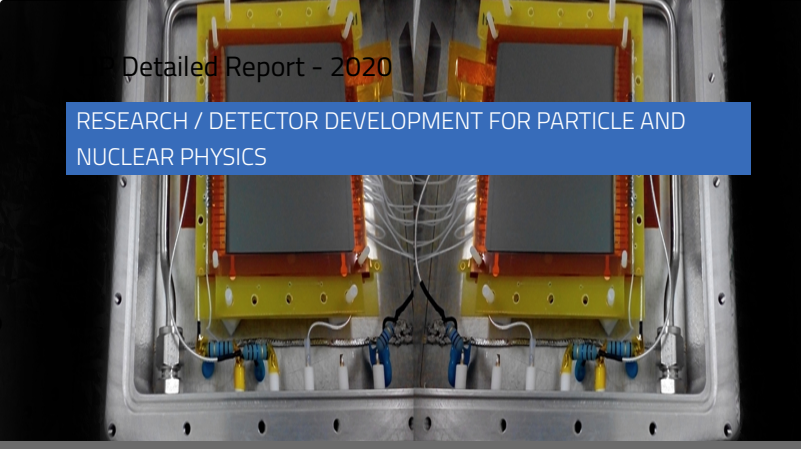
1 Poster presentation(s) in national conference(s)

- Diogo Gonçalves: *"Um dispositivo móvel baseado em RPCs para tomografia de muoes"*, 2020-09-02, FÍSICA 2020 - 22ª Conferência Nacional de Física, Lisboa

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)



NEUTRON DETECTORS

Neutron detectors

Principal Investigator:
Luís Margato (65)

3 ***Researcher(s):***
Alberto Blanco (5), Andrey Morozov (40), Paulo Fonte (10)

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

Total FTE:
1.2

Articles in international journals:
2 Direct contribution
International conferences:
1 Oral presentation
International meetings:
1 Oral presentation

Executive summary

The importance of neutron-based methods 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 currently under construction. Neutron-based techniques are a powerful tool for locating deuterium and hydrogen atoms in the crystal structure of biological systems, needed to reveal structural and dynamic aspects nearly invisible to X-rays. These techniques rely on modern neutron diffraction and reflectometry instruments, which, to fully realize their potential, require neutron detectors with characteristics beyond the current state-of-the-art. Therefore, the development of new neutron detection technologies is important, especially considering neutron scattering applications at the high flux neutron sources, such as J-SNS in Japan, SNS in the USA and ESS in Europe.

Our group is developing neutron detectors for more than a decade. We have established fruitful collaborations with the detector groups from the world-leading European neutron facilities, including ILL, ISIS and TUM-FRMII, and participated in several large EU-funded projects, such as NMI3-FP6, NMI3-FP7 and SINE2020-H2020. Recently we have introduced a promising ^{10}B-RPC neutron detection technology, which we are currently developing aiming at applications in neutron scattering science. Based on the studies conducted in the framework of the SINE2020 H2020 project the potential of the ^{10}B-RPC technology for the development of high-resolution position-sensitive thermal neutron detectors (PSND) is now recognized by the scientific community. Four papers describing the detector concept, experimental feasibility tests at neutron beam facilities, a study of the neutron imaging capabilities and the results of a simulation study dedicated to optimization of the concept were published in peer review journals and two more papers are currently being prepared.

Our main goal is to experimentally demonstrate that the ^{10}B-RPC detection technology has high counting rate capabilities, required by the applications at the modern high flux neutron sources. We plan to construct a detector able to operate at counting rate densities above 100 kHz/cm^2 without compromising the high detection efficiency and spatial resolution demonstrated before.

Sources of funding

PI	Code	Amount	Dates	Description
Alberto Blanco	CERN-FIS-INS-0009-2019	70.000 €	2020-01-01 / 2021-12-31	RPCADVANCE : Advancement of the RPC detector technology targeting CERN experiments and applications for society

Total: 70.000 €

Overview

The research activities of the group are centred on the development of innovative thermal neutron detectors for 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 team is composed by four researchers having extensive knowledge in the development of detectors for particle and nuclear physics: Luís Margato (group coordinator), Andrey Morozov (responsible for Monte Carlo simulations and image reconstruction studies), Alberto Blanco (an expert in the area of RPC detector development) and Paulo Fonte (an expert in the physics of RPC detectors). The research line of the group has a strong synergy with the activities conducted in the RPC R&D Group at LIP.

Currently our studies are aimed at demonstrating that the ^{10}B-RPC technology can be used to construct PSNDs capable of meeting the strict requirements defined for new neutron scattering instruments planned at the large-scale facilities (LSF), focusing, in particular, in the ESS.

The main lines of work are:

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

The new neutron facilities with high flux sources put strong rate requirements on the detectors. An improvement in the counting rate of ^{10}B-RPCs can be achieved mainly by (1) using electrode materials with lower resistivity, (2) reducing the electrode thickness, (3) decreasing the electrode resistivity by increasing the operation temperature and (4) implementing the so-called multi-layer or jalousie detector architecture.

The research activities include tests of new materials with a bulk resistivity in the range 10^9-10^{10} Ω·cm, development of new detector designs based on multi-layer and jalousie architectures, Monte Carlo simulation studies targeting the design optimization and work on the data acquisition and analysis tools.

- **Reduction of the background**

Neutron detectors often operate in an environment with strong gamma background. To make an effective imaging detector for such conditions, it is mandatory to provide good neutron/gamma discrimination.

The research activities include both optimizations of the RPC design (simulations and prototyping) as well as basic research since there are still unknowns in our understanding of the operation of RPCs, especially as neutron detectors.

- **Optimization of the signal readout and position reconstruction methods**

There is the potential to reach 0.1 mm (FWHM) spatial resolution, opening new possibilities for neutron science instrumentation. Work is ongoing on the optimization of the signal readout and implementation of new image reconstruction methods, such as statistical reconstruction, targeting a significant increase in the image linearity and uniformity.

Assessment of the past year: objectives vs. achievements

Single-gap ^{10}B-RPCs with anodes made from a low resistivity glass and a ceramic composite have been tested in 2019 at a neutron beam. This year we have finished the analysis of the data. A paper reporting the findings has been written and will soon be submitted for publication.

For the year 2020 it was planned to evaluate such materials and other new candidates for the resistive anodes in terms of homogeneity, aging effects, minimum thickness and robustness, and to characterize their counting rate capability, operation stability, dark current and scalability to large areas. As a consequence of the COVID-19 outbreak, it was not possible to manufacture several critical detector components, nor to travel abroad for beam tests. Therefore these studies were postponed.

Two objectives for 2020 were related to the reduction of the detector background:

- Perform GEANT4 simulations to study the effect of the new materials on the RPC gamma sensitivity and neutron elastic scattering inside the detector.
- Optimize the detector configuration targeting a decrease in the energy deposition in the gas gap due to Compton electrons in order to reduce gamma sensitivity.

The ^{10}B-RPC detector background is affected by two major factors: elastic scattering of neutrons on the detector components and sensitivity of the detector to gamma rays. Neutrons which had at least one elastic scattering before detection do not provide useful spatial information and thus only contribute to the background. Therefore, the materials having the strongest contribution to the scattering have to be identified and realistic modifications of the detector design minimizing scattering have to be considered.

Detailed detector simulations with the GEANT4 and ANTS2 toolkits were performed, allowing to quantify the contributions from all the detector materials to the elastic scattering of neutrons. It was found that glass is the main contributor, thus the thickness of the glass anodes should be reduced to the minimum commercially available thickness of 0.28 mm. The second contributor is the polyimide films holding the signal pickup strips. We found that it should be possible to completely avoid the usage of these films by depositing the signal pickup electrodes directly on the back surface of the resistive anodes. This solution has triggered an ongoing search for a new way to connect the signal pickup strips to the front-end electronics. The last significant contributor is the aluminium cathode plates. Their thickness can be reduced from 0.5 mm to 0.3 mm. Below this value the electrode plates were found to become too flexible, which negatively affects the uniformity of the gas-gap width. The simulation results show that a reduction of at least a factor of 2 in the background events, generated by neutrons scattered in the detector, is feasible by implementing all the changes listed above.

Simulations of the energy deposition in the gas-gap from gamma rays (1 MeV) have shown that the reduction in the thickness of both glass and aluminium plates, as well as a decrease of the gas-gap width from 0.35 mm to 0.2 mm, lead to a decrease in the gamma sensitivity of a factor of ten.

Previously it has been shown that a detector with multiple ^{10}B-RPCs arranged in a multilayer configuration can have its counting rate capability improved by more than one order of magnitude, independently of the resistivity of the electrode materials. The effect of neutron scattering inside a detector comprising a stack of 10 double gap ^{10}B-RPCs was analyzed and modifications with respect to the design of the first detector prototype tested at FRM II (MLZ-Heinz Maier-Leibnitz Zentrum, Germany) were suggested to minimize this effect. Results obtained with ANTS2 and GEANT4 are quite similar, with the exception of a significantly weaker scattering in Al and Cu given by the simulations performed in ANTS2 with enabled NCrystal library. This fact can be explained by taking into account that NCrystal computes the scattering cross-section using information on the structure of the crystal lattice, which is not considered in GEANT4.

Another objective for 2020 was to investigate the performance of several position reconstruction methods in order to improve the image linearity and uniformity.

The datasets recorded in 2019 with a double-gap ^{10}B-RPC detector with flood-field illumination, as well as using gadolinium masks with narrow slits, were used to characterize the performance of the position reconstruction with the Center of Gravity (CoG) method. The experimental datasets with a single slit mask positioned at a regular grid of positions allowed to reconstruct the so-called PRFs (pad response function), which are the profiles describing the dependence of the induced signal on the distance between the event position and the center of the readout strip. An analytical parameterization for the PRF was developed. The PRFs, in turn, were used in the statistical image reconstruction (SR). We have demonstrated that the SR has an advantage over CoG considering the image linearity and uniformity due to much better capability to filter "bad" events (events distorted by electronic noise, dark events or double events). SR finally allowed to explain why the apparent resolution of the detector is different in X and Y directions: we have demonstrated that this effect arises from the fact that the detector has a double-gap RPC, and the Y electrodes for the two gaps have a slight (~0.15 mm) mismatch in their positions, resulting in a small blurring of the reconstructed images in this direction.

The group has prepared and submitted proposals for the PT-CERN PhD Grant Programme, edition 1 and 2, and the call for grants for Master in Physics Engineering at the Department of Physics of the University of Coimbra. Unfortunately, we were unsuccessful. The group also prepared and submitted a proposal to the PTDC-2020 call from FCT. The project was evaluated positively and the evaluation panel commented: "*This is a fine project*"; "*It is good for Portugal to keep this activity*". However, it was not considered for funding due to very high competition and a very limited call budget.

Lines of work and objectives for next year

During the next year we plan to design, optimize and construct a prototype of a ^{10}B-RPC detector proposed in the FCT-funded RPCADVANCE project. It is intended to demonstrate the possibilities of ^{10}B-RPC neutron detectors in terms of counting rate capability. The detector should be able to handle high local counting rates on the order of 100 kHz/cm^2. In addition, the detector must have a high thermal neutron detection efficiency (>50%) and submillimetric spatial resolution. This line of work is to be developed in close collaboration with the RPC R&D Group.

It is also planned 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 in experiments namely in ISOLDE at CERN. This line of work is to be developed in a close collaboration with the NUC-RIA Group.

The planned activities and objectives for the next year are the following:

- **Construction of a high-counting rate, high efficiency ^{10}B-RPC detector**

The main objective is to design and build a detector with double-gap ^{10}B-RPCs arranged in a multilayer architecture in order to achieve the target counting rate density (~100 kHz/cm^2) and a detection efficiency of about 50%.

Optimization of the detector design will be performed with the ANTS2 and GEANT4 toolkits. A strong attention will be paid to maximize the counting rate without compromising the low background level, which is affected by elastic neutron scattering and sensitivity to gamma rays.

We will conduct an evaluation of the materials selected for the resistive anodes in terms of, e.g., minimum thickness and robustness, scalability to large areas, homogeneity, counting rate capability, operation stability, dark current and aging effects.

The next step will be manufacturing of the detector components at the LIP Mechanical Workshop. The deposition of the $^{10}B_4C$ converter layers enriched in ^{10}B onto the RPC aluminium cathodes will be performed at the ESS detector coatings workshop (already established collaboration).

The detector is to be interfaced with the data acquisition system developed by the RPC R&D Group. The previously developed TRB reader + ANTS2 tool chain will be adapted to manage the data acquisition and analysis.

The detector will be tested in our lab to evaluate and fine-tune the operation conditions, and then characterized at a neutron beam at FRMII (Germany). Note that the possibility to perform the beam tests next year is still undefined due to the pandemic.

- **^{10}B-RPCs as a detector for delayed-neutron emission**

This research line aims to investigate the possibility to apply ^{10}B-RPC technology for detection of neutrons with a broad energy spectrum in the range 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. As main requirement, the detector should provide good (~50%) detection efficiency with a flat response up to the neutron energy of about 2 MeV. It should also have a low background.

The study will be performed using detailed simulations with ANTS2 and GEANT4. We will consider different detector configurations, in which ^{10}B-RPCs detection blocks are alternated with polyethylene (or paraffin) neutron moderators.

The potential characteristics of such ^{10}B-RPC-based detectors will be compared to the corresponding parameters of the detectors already used for similar applications (e.g. based on ^{3}He detection technology).

Medium-term (3-5 years) prospects

The next generation of diffractometer and reflectometer detectors at spallation sources requires spatial resolution in the millimeter range up to about 0.1 mm (FWHM) and local counting rate capability ranging from tens of kHz/cm^2 to MHz/cm^2, depending on the application. For example, detectors for macromolecular diffractometers should have a spatial resolution below 0.2 mm (FWHM) simultaneously with TOF capability. Detectors should also have detection efficiency of about 50%, gamma sensitivity below 10^{-6} and exhibit excellent response uniformity and long-term stability. Spatial resolution and counting rate capability are the two most difficult requirements to satisfy for this class of detectors. In the medium term, the group aims to push forward the development of the ^{10}B-RPCs technology to realize a demonstrator of a ^{10}B-RPC based position sensitive neutron detector and perform its characterization on a neutron beamline in partnership with our colleagues from a neutron facility (ILL, ISIS and/or FRM II). The main objective is to meet the aforementioned detector requirements and particularly push the counting rate capability of ^{10}B-RPC based detectors beyond 100 kHz/cm^2.

If the results of our study on the possibility of applying ^{10}B-RPCs for the measurements of the probability of the beta delayed neutron emission from very exotic nuclei (e.g. ISOLDE at CERN) are positive, we plan to continue this line of research. We will conduct a detailed MC simulation/optimisation of the detector concept and perform a series of preliminary experimental validations jointly with the NUC-RIA and RPC R&D groups. As next step we will apply for funding for the development of a full-scale detector demonstrator.

Also, in the medium-to-long term, we are considering prospects for developing a fast neutron spectrometer for real-time measurements. This new line of research has a potential in the field of medical applications, such as, e.g., neutron dose monitoring in hadron therapy.

We plan to strengthen synergies with the detector groups from the world-leading neutron facilities (ESS, ILL, ISIS and FRMII) and maintain the capability to develop innovative detectors for frontline research. This is strategic for future funding opportunities within the next EU framework programme Horizon Europe.

SWOT Analysis

Strengths

Team with an extensive knowledge of detector physics and experience in all the stages of detector development.

Long-standing collaboration with international partners from world-leading large scale neutron facilities, which provides access to neutron facilities and brings new financing opportunities based on EU funds.

Access to the Detectors Lab and Mechanical Workshop at LIP-Coimbra.

Weaknesses

Manpower is quite limited: the group's combined FTE is about 1.2. It has been difficult to attract PhD students and postdocs due to lack of funding.

Opportunities

The European Spallation Source, which is currently under construction in Sweden, is driving the development of new types of thermal neutron detectors.

Our ^{10}B-RPC detection technology demonstrates a strong potential for applications in large scale neutron facilities due to the capability to deliver a combination of characteristics impossible to achieve with the competing technologies.

Threats

The restrictions and delays in access of the neutron beamlines at large-scale facilities as the consequence of the pandemic.

Very limited and not-sustainable funding.

Neutron Detectors

Publications

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

- *"Simulation-based optimization of a multilayer B-10-RPC thermal neutron detector"*, A. Morozov, L. M. S. Margato, I. Stefanescu, J. Instrum. 15 (2020) P03019
- *"Multilayer 10B-RPC neutron imaging detector"*, L.M.S. Margato, A. Morozov, A. Blanco, P. Fonte, L. Lopes, K. Zeitelhack, R. Hall-Wiltond, C. Höglund, L. Robinson, S. Schmidt, L.M.S. Margato et al 2020 JINST 15 P06007

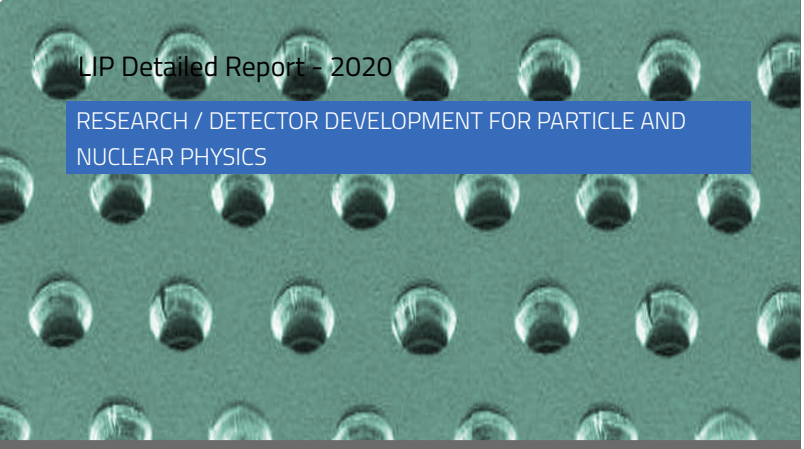
Presentations

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

- Luís Margato: *"Towards high counting rate RPC-based neutron detectors: current state and perspectives"*, 2020-02-11, XV Workshop on Resistive Plate Chambers and Related Detectors RPC2020, University of Rome "Tor Vergata", Italy

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

- Luís Margato: *"10B-RPC based Neutron Imaging Detectors"*, 2020-02-16, Jornadas LIP - 2020, Universidade do Minho - Campus de Gualtar, Braga, Portugal



GASEOUS DETECTORS R&D

Gaseous Detectors R&D

Principal Investigator:
Filomena Santos (24)

8 ***Researcher(s):***
Afonso Paixão Marques (100), André Cortez (24), Carlos Conde (14), David Marques (100), Filipa Borges (24), Jorge Maia (15), José Escada (54), João Barata (24)

1 ***PhD Student(s):***
Alexandre Fonseca Trindade (54)

1 ***Master Student(s):***
Afonso Paixão Marques (80), David Marques (80), Miguel Santos (100)

1 ***Trainee(s):***
Nicole Duarte

Total FTE:
7.0

Articles in international journals: **3** Indirect contribution

Completed theses: **2** Masters

Executive summary

The Gaseous Detectors R&D Group develops research in 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, both 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 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 occurring 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 the measurement 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 an actual and very important issue.

Sources of funding

PI	Code	Amount	Dates	Description
Vitaly Chepel	CERN/FIS-INS/0025/2017 (Gaseous Detectors R&D)	70.000 €	2018-05-01 / 2020-04-30	Participation in the RD51 Colaboration (Gaseous Detectors R&D)
Vitaly Chepel	CERN/FIS-INS/0026/2019 (Gaseous Detectors R&D)	35.000 €	2020-11-01 / 2022-10-31	Participação em colaboração RD51 no CERN para desenvolvimento de detectores de partículas em microestruturas

Total: 105.000 €

Gaseous Detectors R&D

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, transverse and longitudinal, and drift velocities (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 have a functional dual polarity ion drift chamber. This goal was fully achieved as the previous prototype was assembled, tested and improved. First results for SF6 gas and SF6-CF4 and SF6-N2 mixtures were obtained and compared with the ones available in literature. The results were shown to be in accordance with the published results or with the ones expected from Blanc's Law or from Monte Carlo simulations developed for particular cases, when experimental results were not available for comparison. The use of this device for the measurement of positive ion mobility was also tested and, although the precision is not as good as the one obtained with the previous positive ion mobility chamber, it still led to consistent results. In this part some improvements are necessary. Further work with this chamber for other electronegative gases, and the upgrade for higher pressure still needs to be done.

Within the NEXT collaboration, a subject needing attention was the origin of the undesirable spurious pulses observed in the NEXT electroluminescence TPCs (and in other double-phase dark matter experiments and high pressure xenon TPCs). A prototype was developed to study the possibility of these being due to photoelectrons released from the TPB, frequently used in these chambers as wavelength shifters. The prototype is a stainless steel cylinder which has on one of the tops a VUV xenon lamp and on the other a removable stainless steel flange. This flange will be deposited with CsI for calibration at first and, later on, with TPB. Above this flange there is a charge collecting grid that will collect and allow the measurement of the current eventually produced by the xenon VUV light on the deposits. The system was designed and assembled and the first tests are being made. These results will be reported in NEXT collaboration meetings as soon as they are available.

Also the system designed to measure the electron drift coefficients in gases is fully functional and measurements are being performed. Results for xenon were already obtained and are being analysed and compared to available data, both experimental and from simulations developed to replicate the experimental system. We will now proceed to a molecular gas, for which results are very different, to verify the consistence and reliability of the device. Later on, once the consistency of the results obtained with this device is fully assessed 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). The developed simulation codes will also be adapted for these mixtures.

Lines of work and objectives for next year

During the next year the required improvements in the dual polarity ion mobility measurement system will be studied and implemented and more experimental measurements will be performed, for different mixtures and pressures. The interpretation of the results will be fully explored and comparison with available results from the literature will allow the validation of the system. The upgrade of this system to allow the measurement of ion mobilities at higher pressures, namely near atmospheric one will be considered and is a task of the recently approved project for participation in the RD51 Collaboration at CERN in which the team is involved.

Our involvement in the NEXT Collaboration will continue and the questions raised within the collaboration in the understanding of the behaviour of gas mixtures, namely at microscopic level, that influence the performance of the presently working prototype (NEW-White) will be studied. Also, the study of negative ion mobility can be of interest for the future in NEXT, if the use of electronegative ions is considered. Since the use of negative ions as charge carriers is recently growing, we intend also to study the many features associated with the use of electronegative gases as dopants, namely the efficiency of attachment of electrons to the electronegative molecules, the conditions needed for their release, the ability of these gases to amplify the charge signal, either through electron charge multiplication or light production.

Further results for electron drift parameters and drift velocities will be obtained for different (and potentially interesting) gases and their mixtures. These will be studied for specific applications, namely for detection of polarized radiation.

Within the frame of the RD51 collaboration, measurements of positive and negative ion mobility will continue, for mixtures considered of interest.

The improvement of HPXe detector already developed and tested for alpha particles, allowing its use for detection of high energy X-rays and gamma-rays is also one in our perspective. This work, however has been depending on financing and availability of man-power.

Also, new international or national collaborations will be sought for, within our fields of knowledge.

Medium-term (3-5 years) prospects

The objective of the Gas Detectors group for the upcoming years is to develop novel geometries for gas detectors, with the aim of eventually producing an industrial prototype and answer to the needs in the challenging 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. Monte Carlo simulation expertize, with custom made and adaptable codes, will also be an invaluable asset either as a first approach or as a cross check to potential interesting features.

The study of electroluminescence for gaseous mixtures using electronegative dopants to decrease electron diffusion - an important feature in large scale, high pressure experiments is also a field that may be explored and originate further collaborations with groups that are interested in this area. A special focus will, of course, be maintained on the needs of the NEXT and RD51 collaborations and new collaborations within our area of expertise will be sought.

So, future work for the next 5 years will also depend on issues that will arise in the collaborations we integrate (and others which we will seek), in the case of NEXT, namely with the assembly and first tests with the 100 kg TPC and also on the available funding and human resources that have been very uncertain in the last years.

SWOT Analysis

Strengths

The group has developed a cohesive set of topics and related experimental tools as well as Monte Carlo development techniques, within the framework of research for the improvement of the performance of gas detectors. These topics include the most important features of gas detectors and enable an integrated multidimensional study.

Weaknesses

The main challenges will be to publicise the expertise developed along the years to the scientific community in order to establish collaborations with other groups which will hopefully generate funding.

Opportunities

These come basically from international contacts, awareness and knowledge of our work. Our work has been expanded to the Astrophysics domain, where new gas mixtures for polarimetric studies are being sought. Our experimental system can be an important asset to fulfill the information gaps, and our Monte Carlo simulation skills, with custom made adaptable code, is a first approach to potentially relevant mixtures to study - together they are simultaneously strengths and opportunities.

Threats

Lack of financing conditions the whole activity of the group, from experimental development of prototypes to human power and dissemination of achievements.

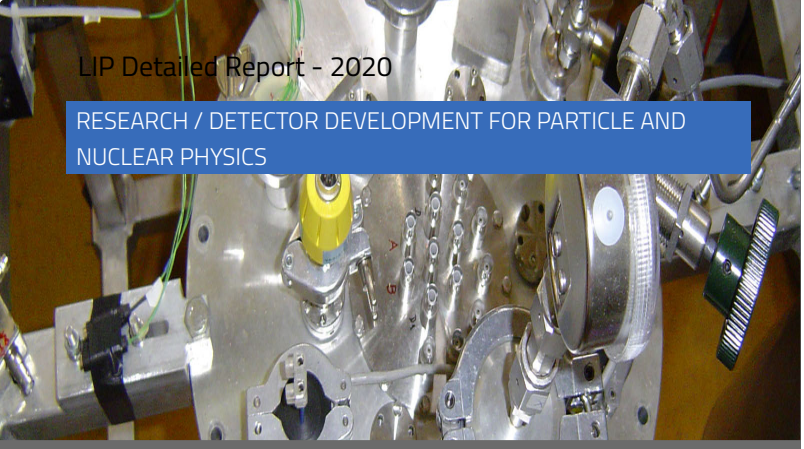
Theses

1 PhD

- Alexandre Fonseca Trindade: *"Study of noble gases mixtures characteristics as a detection medium"*, 2017-01-01, (ongoing)

3 Master

- Afonso Paixão Marques: *"Calibration of the NEXT-DEMO++ Electroluminescent Time Projection Chamber Within the NEXT Experiment"*, 2019-09-01 / 2020-10-25, (finished)
- David Marques: *"Negative ion mobility measurement in gases of interest for NITPCs"*, 2019-09-01 / 2020-10-25, (finished)
- Miguel Santos: *"Development of a Negative Ion Drift Chamber and Study of negative ion transport properties in gaseous mixtures of interest"*, 2017-09-01, (ongoing)



LIQUID XENON R&D

Liquid Xenon R&D

Principal Investigator:
Vitaly Chepel (19)

4 ***Researcher(s):***
Francisco Neves (10), Luís Margato (12), Rui Marques (12), Vladimir Solovov (10)

Total FTE:
0.6

International conferences: **2** Oral presentations

Executive summary

There is a number of experiments around the world using liquid xenon as detector medium. These include search for lepton number violating muon decays, dark matter searches, neutrino physics and double beta decay. Although the energy ranges of interest of these experiment are different, they have very much in common from the detection point of view. The general idea of this 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 that are not 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	Code	Amount	Dates	Description
Vitaly Chepel	CERN/FIS-INS/0025/2017 (Liquid Xenon R&D)	70.000 €	2018-05-01 / 2020-04-30	Participation in RD51 (Liquid Xenon R&D)
Vitaly Chepel	CERN/FIS-INS/0026/2019 (Liquid Xenon R&D)	35.000 €	2020-11-01 / 2022-10-31	Participação em colaboração RD51 no CERN para desenvolvimento de detectores de partículas em microestruturas

Total: 105.000 €

Liquid Xenon R&D

Overview

The general purpose of the group is to carry on R&D on liquid xenon physical properties and instrumental/technological issues relevant for development of particle detectors based on liquid xenon (and eventually other liquefied noble gases). The group consists of three senior members, all being PhDs in the field.

Assessment of the past year: objectives vs. achievements

In the past year, the project CERN/FIS-INS/0025/2017, where the group was responsible for one of the four tasks, has been completed. The experimental setup, previously mounted for the preliminary tests, has been further developed and mostly assembled. As planned, the setup allows studies of the effect of the ultraviolet light on electron and eventual fluorescence emission from various materials frequently used for detector construction (e.g., PTFE, copper, stainless steel) to be measured. The charging of dielectric materials such as PTFE can also be studied. The setup is equipped with a xenon flash lamp, VUV filter to select the xenon emission line at 175 nm, and the test chamber with a MgF2 window. The chamber also has two other ports that can be used for different purposes, namely for power and high voltage supply and signal readout. Inside the test chamber, a variety of experimental arrangements can be allocated. For the purpose of this particular experiment, a two electrode system is used. The sample is mounted on the cathode and the emitted electrons collected on the grid anode. Through that the sample is illuminated with the VUV light. The VUV induced secondary light emission can be detected with a set of SiPMs. The foreseen measurements have not been completed due to a general disturbance of the normal experimental activity due to COVID-19 as well as delays in delivering the necessary materials.

Lines of work and objectives for next year

To work on the framework of CERN/FIS-INS/0026/2019 project started in November 2020. Develop a setup for studying THGEM behaviour on the surface of liquid xenon.

Medium-term (3-5 years) prospects

For the next 2 years, to work in the framework of the RD51 project on studying instrumental issues and physical processes in liquid xenon relevant for particle detection. Uncertain in the scope of 5 years.

SWOT Analysis

Strengths

Highly qualified members of the laboratory 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 disinvestment.

Opportunities

Overcoming the weakness, there is an opportunity of understanding some fundamental aspects of the detector physics and provide a valuable input for future large scale detector development in the framework of the funded projects "Participation in the RD51 Collaboration at CERN".

Threats

Limited availability of human power. Lack of investments and investment policy. Low priority at LIP.

Liquid Xenon R&D

Presentations

2 Oral presentations in international conferences

- Vitaly Chepel: *"Liquid Xenon TPCs"*, 2020-10-07, Workshop on New Horizons in Time Projection Chambers, Santiago de Compostela
- Vitaly Chepel: *"Scintillation Properties of Liquid Xenon Relevant for Fast Ion Spectrometry"*, 2020-12-17, Workshop on Techniques and Detectors for Heavy Ion Charge Identification in High Acceptance Spectrometers,, University of Michigan (online)

[Instruments and methods for biomedical applications]

Proton Therapy

OR Imaging

Dosimetry

RESEARCH / INSTRUMENTS AND METHODS FOR BIOMEDICAL APPLICATIONS

PROTON THERAPY

Introduction

LIP is a founding member of the Portuguese Network of Infrastructures for Proton Therapy and Advanced Technologies for Cancer Prevention and Treatment (ProtoTera), jointly with the Portuguese Institute of Oncology Hospital Group, Instituto Superior Técnico, and the University of Coimbra (Resolution of the Council of Ministers n. 28/2018). ProtoTera will promote and develop a national network for research, education and treatment of cancer using advanced technologies, such as proton therapy. In the initial phase, it will coordinate the construction of two nodes in Lisbon and Coimbra, with a 250 MeV proton accelerator coupled to two treatment rooms and one research room in Lisbon, plus a 70 MeV accelerator for the treatment of ocular melanoma and theranostic radioisotope production in Coimbra, which are expected to be operating by 2026. Several important research lines include: toxicity, organ mobility, improvement in dose distribution, in vivo dosimetry and dose estimation. At the same time basic research, imaging, and data computing technologies are core to the success of the infrastructure. Furthermore, radiobiology is an important research axis. R&D activities with good cross-fertilization prospects will also be carried on such as the development of radiation detectors, imaging devices and techniques, and studies of radiation effects on electronic devices.

This list matches the competences of several research groups at LIP, with already secured funding in collaborative projects with companies. Close collaborations with international reference centres are being established, namely with CERN, GSI, the Heidelberg University Hospital (Germany), the MD Anderson Cancer Center (USA) and the Trento Proton Therapy Center (Italy).

LIP'S R&D activities directly related with charged particle therapy presently include thedevelopment of an orthogonal prompt-gamma imaging (O-PGI) system for monitoring proton therapy and of a PET-ToF system for range verification in proton therapy, which is being developed with the industry and other national and international partners under the UT Austin-Portugal Programme. These projects are both described in the **OR Imaging Research Group** detailed report and will have demonstration prototypes ready in the next couple of years. Their next technology development stages, as well as future projects based on the acquired know-how, will benefit greatly from the existence of a National facility in which they can be tested and validated. LIP, through the **Dosimetry Research Group** (see detailed report) is also engaged in radiobiology projects, namely the study of accurate dose delivery to skin cells by protons, for which new microdosimetry instruments are being developed. Additionally research in the area of FLASH proton therapy and on the use of proton mini-beams to reduce the toxicity to healthy tissues is also being performed in collaboration with João Seco from the German Cancer Research Center (DKFZ) and the Heidelberg University Hospital.

The two LIP Research groups, OR Imaging and Dosimetry, and several LIP researchers are therefore involved in the effort of developing a structure at LIP that can contribute to the advancement of charged particle therapy in Portugal.
Advanced training is a fundamental aspect of LIP s strategy for charged particle therapy, allowing to train experts, to promote collaboration between LIP researchers and between LIP and external collaborators and experts.

A PhD grant programme was created in 2020, under an agreement between FCT and ProtoTera. The first call on the Prototera grants had its first 5 grants awarded in January 2021. One of the grants was awarded to a student starting a PhD

in Biophysics and Bioengineering (FCUL, University of Lisbon) under the supervision of Jorge Sampaio, the LIP Dosimetry group PI (modelling the radiobiological effects of gold nanoparticles in proton therapy of glioblastomas). Additionally, there were **several applications on charged proton therapy to the first and second PT-CERN PhD programme calls in the domain of "Technologies associated to the Portuguese participation at CERN and their transfer to society".** Three PT-CERN PhD grants were awarded to students under the supervision of LIP researchers. They will take their PhD at the University of Lisbon, under the supervision of Jorge Sampaio or Patrícia Gonçalves, in co-supervision with Paulo Crespo, PI of the OR Imaging group, or with João Seco (German Cancer Research Center (DKFZ), Heidelberg University). **Several Master students are also developing their theses in the framework of the different activities of the OR-Imaging and Dosimetry groups** (see group reports for further details). LIP researchers were also involved in the creation of a **minor in Medical Physics at IST**, which was approved and will be offered in the curricula of all engineering degrees.

RESEARCH / INSTRUMENTS AND METHODS FOR BIOMEDICAL APPLICATIONS

OR IMAGING

Orthogonal Ray Imaging for Radiotherapy Improvement

Principal Investigator:
Paulo Crespo (65)

2 ***Researcher(s):***
Andrey Morozov (40), Hugo Simões (100)

2 ***Master:***
José Teodoro (*), Margarida Simões (*)

Total FTE:
2.1

(*) Starting in 2021

Advanced Training Events: **1** Oral presentation
National or International meetings: **3** Oral presentations

Executive summary

The work of the OR Imaging group is divided into three main branches: OrthoCT (orthogonal computed tomography) for monitoring external, megavoltage-based radiotherapy (i.e. high-energy X-rays); O-PGI (orthogonal prompt-gamma imaging) for monitoring proton therapy treatments; and the activities within the TPPT consortium (in-beam time-of-flight PET for proton therapy).

For Ortho-CT in 2020 we have managed to compile the experimental results obtained previously in-beam, within the irradiation of a phantom with high-energy X-rays from a therapeutical linac located at the Radiotherapy Department of Coimbra University Hospital Center (CHUC, EPE). These results are going to be submitted in short time to an international scientific journal. They regard a first-time, 3D observation of an air cavity located inside a polymethyl methacrylate (PMMA) phantom with the OrthoCT technique, i.e. 3D imaging without rotation neither the irradiated phantom nor the X-ray source. Such technique may be useful either on the detection of patient morphologic changes during therapy, or in the so-called on-board imaging, i.e. imaging the region that is about to be irradiated, with the patient lying already in the treatment position.

Regarding O-PGI, during 2020 the group undertook extensive GEANT4 simulations in order to optimize an O-PGI device for monitoring proton therapy treatments in the head region. Tens of thousands of CPU hours were utilized on the high performance computing cluster of the University of Coimbra, the Navigator. The optimization included obtaining the thickness, height, length, and air-slice width of the collimator slats that yielded the best precision for determining the location of the Bragg peak. For that, a beam with 1E8 protons (typical in head irradiation) was distributed in time slots of 10 ns (bunch repetition period) for a total time length of 3.23 ms. The time of flight (TOF) of the prompt gammas, being shorter than that of the escaping neutrons, allowed for a large rejection of the latter, so that a Bragg peak position precision of ca 2 mm full width at half maximum was achieved in the simulations (not possible without TOF-based neutron rejection). This Monte Carlo also comprised the optimization of the scintillators positioned in between the tungsten slats, including the first-time propagation of the optical photons generated in the YAP crystals, and their detection by an optical sensor. In summary, all details are met for the construction of an O-PGI system for monitoring proton therapy treatments in the head-and-neck region. Planned activities for 2021 are already underway. They include the optimization of an O-PGI system for monitoring proton treatments in the pelvic region (e.g. pelvic bone nearby the spinal cord and prostate irradiation). Here, the higher beam energy of 200 MeV, instead of the 130 MeV for the head irradiation, and larger penetration depths result in a much higher number of scattered photons and neutrons being produced. Therefore the O-PGI system must again be optimized via GEANT4-based simulations.

Finally, the TPPT consortium is, since January 2020, thriving efforts in order to bring an in-beam TOF-PET system onto one of the proton beam lines in the MD Anderson Cancer Center (MDACC) in Houston, Texas, USA. The team at LIP is responsible for the simulations that will allow a comparison between measured beta+ activity distributions versus the expected ones. Member of the consortium are: PETsys Electronics (leading company), LIP, University of Lisbon, University of Coimbra, University of Texas at Austin, and MDACC.

Sources of funding

PI	Code	Amount	Dates	Description
Paulo Crespo	CERN/FIS-TEC/0019/2019	90.000 €	2020-01-01 / 2021-12-31	Raditherapy with protons: real time imagiology with gammas and microdosimetry
Paulo Crespo	LISBOA-01-0247-FEDER-045904	200.442 €	2020-01-01 / 2022-12-31	TPPT - Time of flight PET for Proton Therapy

Total: 290.442 €

OR Imaging

Overview

This is LIP's core project in instrumentation for radiation therapy, and 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.

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 two recently approved projects which will have an important impact in the future activities:

- "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 in the next two years, approved by the CERN fund.
- "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. LIP is represented by the PI of the OR Imaging group.

As an example of recent progress, the results of the analysis of a cavity irradiated inside an acrylic, cylindrical phantom using a small-scale OrthoCT system recently proved for the first time that it is possible to obtain 3D images of the interior of an object without rotating neither the X-ray source nor the object being imaged. As for 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.

Assessment of the past year: objectives vs. achievements

Last year three lines of work were foreseen: (1) development by software of a full OrthoCT system, including optimization of crystal granularity and its positioning at the end of the multi-slice collimator or embedded into it; (2) development also by software of a full-scale O-PGI system for monitoring proton radiotherapy, which also should include crystal granularity and its positioning (OrthoCT and O-PGI detect rays with quite different energies and backgrounds, so that crystal choice and positioning may be different among the two cases); and (3) if funding is granted, construction of a small-scale O-PGI system may be started. The goal is building a 4-parallel slabs system in order to test the feasibility of applying the so-called shifting time-of-flight method for imaging proton beam therapy (PTB) in an experimental facility (e.g. the clinical proton therapy cyclotron in operation at TU Delft, The Netherlands).

With respect to point number (1) above, a full OrthoCT was indeed designed via GEANT4-based simulations. The system optimization considered an irradiation of a tumor lying in the right lung of a digital anthropomorphic phantom (NCAT, NURBS-based cardiac torso phantom). Work is ongoing in order to compare images obtained with crystal-like scintillators positioned in line with the air slices of the multi-slat collimator, with images obtained with a monolithic scintillator positioned beyond the collimator. A monolithic scintillator reduces complexity of construction and offers inferior pricing with respect to the multi-crystal solution. Because the TOF technique is not required in this imaging context, the cheaper (and slower) GSO crystal was considered.

In what concerns the full-scale O-PGI system, tens of thousands of computing hours were utilized in the high-performance computing cluster of the University of Coimbra (Navigator). The result is a fully-optimized system for head-and-neck irradiations, with a Bragg-peak position determination with a precision of 2-mm full width at half maximum. The system includes the scintillators, here chosen to be made of YAP crystals due to their reduced rise-and fall-times, together with the light-detection sensors.

Finally, regarding the construction of a small-scale O-PGI system, it has been completed. This comprises the front-end detectors all the way into the data acquisition system. The latter was chosen to be an ultra-fast, 4-channel oscilloscope capable of recording, without interruption, 3 ms of continuous waveforms running on in its 4 channels. The processing software is already prepared, and beam time has also already been granted by our colleagues from TU-Delft. Only the experiment date has not yet been settled due to the COVID-19 pandemic.

Lines of work and objectives for next year

Lines of work and objectives:

- 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)
- Execute and analyze the in-beam experimental results collected at the clinical proton therapy facility in Delft, The Netherlands.
- 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.

Starting thesis

- José Teodoro (Master in Biomedical Engineering): *Adpating proton therapy treatments to GEANT4 by means of treatment plans based on computed tomograms in the DICOM format (digital imaging and communications in medicine)*, Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

- Margarida Nunes Simões (Master 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*, Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

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.

SWOT analysis

Strengths

The rotation-free, low-dose imaging capability of OrthoCT are two of its great strengths. The imaging capability of OrthoCT has recently been proven by experiment, although based on the FFF mode of irradiation (most modern irradiation technique with X-rays). The on-board patient imaging capability is another potential strength of OrthoCT, together with its real-time imaging making use of the therapeutic beam, possible in some scenarios (irradiation angles) only.

Weaknesses

The high out-of-field photon 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; nevertheless, they come at non-negligible price.

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). OrthoCT represents 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 OrthoCT technique questionable for such sites, at least before the return on previous investment(s) is achieved.

OR Imaging

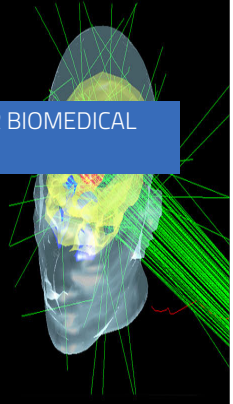
Presentations

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

- *Paulo Crespo: "Particle physics techniques applied to health"*, 2020-07-17, LIP Internship Programme

3 Oral presentations in national or international meetings

- *Paulo Crespo: "Orthogonal prompt-gamma imaging (O-PGI) for monitoring proton therapy: feasibility studies"*, 2020-02-16, Jornadas LIP 2020, Braga
- *Paulo Crespo: "Monitoring proton therapy treatments by means of orthogonal prompt-gamma imaging: a simulation study"*, 2020-02-29, XV Encontro Nacional de Estudantes de Engenharia Biomédica, University of Aveiro
- *Paulo Crespo: "Monitoring proton therapy treatments by means of orthogonal prompt-gamma imaging: a simulation study"*, 2020-07-02, organised by the student branch of the Portuguese IEEE, University of Coimbra



DOSIMETRY

Dosimetry

Principal Investigator:
Jorge Sampaio (60)

3 ***Researcher(s):***
Luis Peralta (40), Pamela Teubig (20), Patrícia Gonçalves (20)

4 ***PhD Student(s):***
Dalila Mateus (50), Duarte Guerreiro (100), José Miguel Venâncio (100), Miguel Molina (*)

7 ***Master Student(s):***
Ana Campos (20), Claúdia Espinha (*), Cristiana Rodrigues (25), Filipa Baltazar (*), Joana Antunes (100), Matilde Santos (30), Nísia Fernandes (8)

1 ***Trainee(s):***
Lia Pereira

Total FTE:
5.7

(*) Starting in 2021

Articles in international journals:	**1** Direct contribution **1** Indirect contribution
National conferences:	**1** Oral presentation
Advanced Training Events:	**1** Oral presentation
Seminars:	**1** Outreach seminar
Completed theses:	**1** Master

Executive summary

In the last two years, the dosimetry group started to establish a research focus in the areas of high-resolution dosimetry and microdosimetry, taking advantage of the competencies it has acquired in the past years in the development of instrumentation, Monte Carlo simulations, and calculation of fundamental physical parameters relevant in dosimetry. This research has implications in emerging modalities in radiotherapy (RT), since it can contribute to improve the data acquisition and analysis of several radiobiology experiments related to FLASH-RT, enhanced RT with nanoparticles (NP), or micro-and minibeam RT (MBRT).

Last year, the group started to work on the development of a new detector system capable of measuring energy depositions at the submillimetric scale using plastic scintillating fibres (PSF). This project proposes the possibility of using the fibre surface as support to functionalized cells. This project fits in the national strategic plan to set up proton therapy (PT) centers in Portugal, that will include physics and biology research beamlines. It uses competencies from different areas forming a multidisciplinary research team, including researchers and technicians from LIP, but also from iNOVA4Health, BioISI/FCUL, C2TN/IST, and ICNAS with experience in bioengineering and radiobiology.

Several studies show that the combination of high-Z nanoparticles and external radiotherapy allows enhanced radiation effect in tumoral cells without increasing the patient dose. However, it is not yet clear how the sequence of physical, chemical, and biological mechanisms contribute to the observed effect. A new line of research started last year to develop simulation tools that allow the analysis and interpretation of radiobiology studies with multifunctional NPs. The work developed so far allowed team members to join tasks in the In-beam Time-of-Flight (TOF) Positron Emission Tomography (PET) for proton radiation therapy (TPPT) project. These are the tasks related to the study of enhanced RT with multifunctional AuNP in glioblastoma multiforme (GBM). Team members also collaborate in tasks of the Prototherapy+ project lead by the OR imaging group.

The group has shown the ability to attract Master students to carry out work on these topics and, for the upcoming years, it has succeeded in obtaining five PhD students funded by the PT-CERN and PROTOTERA programs to collaborate on these projects This group's ability to attract students is driving international collaborations with reference groups in DKZ, Institut Curie/CNRS, and MDACC/UT Austin.

Dosimetry

Overview

In 2020 the group's coordination moved from Luís Peralta to Jorge Sampaio. The LIP dosimetry group collaborates with the OR imaging LIP group in two funded projects: the Prototherapy+, funded by the CERN/FIS-INS/0019/2019 program and in the TPPT project, funded by the UT Austin-Portugal program. Patrícia Gonçalves is supervising a PhD thesis funded by the PT-CERN 2020 call for the instrumentation of the detector prototype developed by the Prototherapy+ project. In the TPPT project, Patrícia Gonçalves contributes to the simulation task coordinated by Paulo Crespo (PI of the LIP OR Imaging group) and Jorge Sampaio collaborates with the C2TN/IST radiochemistry group, sharing the supervision of PhD and Master theses.

The two main lines of research are:

Nanoparticles in RT/Participation in the TPPT project:

The goal of this line of research is to develop skills in the group in Monte Carlo simulations with applications in radiobiology. First work was carried out related to the radiosensitization of cells with Au particles. As a consequence, the dosimetry group integrated the TPPT project in 2020 in a simulation task related to the irradiation of 2D and 3D human GBM cell cultures and xenograft models for different concentrations and distributions of NP. The tasks attributed to the dosimetry group in this project are:

- Development and implementation of 2D and 3D computational models of GBM cell lines in the Monte Carlo simulations.
- Simulation of microdosimetric distributions and ROS distributions in GBM cell lines.
- Implementation of the biological effects model for cell death and strand breaks.
- Prediction of the radiobiological effects and comparison with observed data
- Development of the xenografts GBM on rats' computational model
- Simulation of the dosimetric and reactive oxygen species (ROS) distributions in the GBM on rats' computational model
- Comparison with experimental data.

High-resolution dosimetry and microdosimetry:

The overall goal of this project is to relate the biological effects of skin proton irradiation modalities with measures of dose distribution to the microscale. For this we will use an innovative approach, integrating a functional bioengineered humanized 3D skin model with a new high-resolution real-time scintillating dosimeter concept. This novel concept could be extended to include other organoid systems (eye, etc.), thus opening up the possibility of unprecedented radiobiological experiments at microscales. The dosimeter should be able to perform with very good tissue-equivalence, submillimetric resolution, and nanosecond time-response.

The project has five main tasks:

- Detector development and optimization
- 2D cell and 3D reconstructed skin growth
- Proton beam irradiation setting and radiobiology experiments
- Simulations of 2D and 3D skin radiation effects
- Biological effects assessment and dose measurements

The concept outlined above involves a multi-disciplinary team, where the dosimetry group is the leading partner. This team includes physicists with consolidated experience in scintillation detectors, researchers in bioengineering and cell and molecular biology, and researchers in radiobiology. Two proposals were submitted in 2020, one for an exploratory project 1-year grant (3d-DosSkin), within the UT Austin - Portugal financing program, and the other for a 3-year grant (PRISM) within the IC&DT projects financing program of FCT. Although both proposals were highly praised by the evaluation panel and obtained high marks (7.2/9 and 7.8/9, respectively), this was not enough to be recommended for funding, given the scarcity of grants awarded in each domain.

Assessment of the past year: objectives vs. achievements

The status of the two lines of work mentioned above are as follows

Radiosensitization efficacy of nanoparticles:

This project started with a Monte Carlo simulation work using the TOPAS-nBIO that is an extension to the TOPAS toolkit, based on the GEANT4-DNA extension, including track structure simulations in cell and sub-cellular geometries as well as first physicochemical and chemical reactions. It was developed within the scope of a Master thesis and consisted in the determination of dose enhancement factors (DEF) and temporal distributions of radiolytic yields (G-values) of reactive oxygen species (ROS) for various irradiation conditions. Simulations were performed for protons and X-ray beams in a single cell model with different AuNPs concentrations and distributions. The student's work confirmed that the DEF resulting from intracellular interactions is significantly higher for kV X-ray irradiations when compared to ^{60}Co gamma irradiations or MeV protons. It was also concluded that for high-LET radiation there is a predominance of H_2O_2 and H_2 production, whereas for low-LET radiation, the production of H_3O^+, OH^-, and e_{aq}^- is more relevant. The simpler version of the local effect model (LEM) was also applied to estimate the number enhancement of lethal lesions due to the presence of AuNP in a GBM cell model. It was found again that the most significant effects happen for kV X-rays as the dose increases.

At a more fundamental level, it was planned to perform calculations of updated physical parameters (ionization cross-sections and X-ray and Auger yields) based on state-of-the-art atomic structure

programs, in order to improve the database currently used in microdosimetric simulations. New proton-induced ionization cross-sections were calculated based on the ECPSSR (Energy Loss, Coulomb deflection, Perturbated Stationary State, and Relativistic effects) model for all subshells in the Au atomic system. Calculations of the transition probabilities necessary to determine the X-ray and Auger electrons emission yields (which are the ones that most contribute to the intracell dose enhancement) have also started. These calculations are based on an atomic structure code that implements the MCDF (Multi-Configuration Dirac-Fock) method.

High-resolution dosimetry and microdosimetry:

The goal of this project is to demonstrate the feasibility of a new detector for proton radiobiology studies, capable of measuring with submillimetric resolution and simultaneously supporting the growth of the biological system to be irradiated.

The skin was chosen as the first proof-of-concept biological system because the dose to this organ in PT is often higher than in state-of-the-art photon RT, leading to an increased occurrence of skin toxicities, such as erythema, desquamation, and necrosis. These undesirable effects should be addressed in light of new modalities that propose using sub-millimetric proton beams, which could lead to point doses on the skin comparable to doses at the Bragg peak. More specifically, the project aims at studying the effects of radiation at the microscale in biological 2D and 3D models of the skin for different modalities of irradiation with protons (broad, and single and multi-spot narrow beams).

The detector will be constructed of juxtaposed thin PSF coupled to a readout and acquisition system. The fibres' PMMA cladding will be functionalized to allow cell adhesion. Human keratinocytes will be grown on functionalized fibres in scaffolds either as a 2D monolayer or as an epidermis or both dermis and epidermis for a full 3D human skin. The irradiation experiments will be carried out with proton beams from a radiopharmaceutical production 18 MeV cyclotron. The irradiated cells will be analyzed on what concerns stress and toxicity.

In terms of human resources, we were successful in attracting a PhD student who obtained a scholarship under the PT-CERN program to develop this project. More recently a Master student also joined the project. So far, the tasks carried out include characterization of the photodetector that will be used in the detector, prototyping the connectors between the fiber array and the photodetector, simulations of the experimental protocol for measuring crosstalk effects between the PSFs, and the start of tests with the DAQ. These tasks are being carried out in collaboration with several infrastructures at LIP (LOMaC, e-CRLab, and Mechanical Workshop).

Lines of work and objectives for next year

Nanoparticles in RT/Participation in the TPPT project

The work done in the past year on radiosensitization efficacy of nanoparticles allowed a close collaboration with the C2TN/IST and ICNAS groups involved in the tasks of AuNPs synthesis, irradiation, and biological studies related to the TPPT project, where LIP is the principal institution. The dosimetry group will be responsible for the Animal studies/Dosimetry task. This task consists on the development of simulation tools that allow the analysis and interpretation of radiobiology studies with multifunctional nanoparticles (NPs). To maintain human resources with acquired know-how in this area of study, a work plan was proposed to carry out this task in the scope of the recently created ProtoTera PhD program. The PhD scholarship was recently awarded to the Master student that worked on this subject last year. Therefore, we foresee that the human resources with sufficient skills to develop this task will be enough. The plan includes the development of realistic simulations of the irradiation of monolayer (2D) and spheroid (3D) human GBM cell cultures and xenograft animal models, taking into consideration different concentrations and cellular and subcellular distributions of the Au NPs. We will also investigate feasible ways of simulating irradiations of biological systems with different levels of oxygenation (e.g. normoxia vs hypoxia). Based on these simulations, the dose distributions at the subcellular scale will be obtained, as well as the temporal distribution of the ROS induced by the different irradiation conditions, AuNPs distribution, and concentrations. For the next year, the following activities are foreseen within the scope of the TPPT project: characterization of the physical-chemical properties of NPs to be used in the irradiations, development, and implementation of 2D and 3D computational models of GBM cell lines in the Monte Carlo simulations, and participation on ^{60}Co irradiation campaigns at C2TN/IST.

A new student started her Master thesis in 2021 on the topic of radiosensitization with NPs in external beam radiation therapy. In this work, it is planned to study the radiobiological effect of AuNPs in pancreatic tumor cells when irradiated with photons by means of Monte Carlo simulations. The goal is to study some critical parameters for planning and designing future radiobiology experiments with this type of cell and different characteristics of NPs, namely, using photon beams generated in clinical accelerators (LINACs). The fact that pancreatic cells are particularly radioresistant makes them a good case study where increased radiosensitivity with NPs could significantly benefit clinical practice in the future.

In 2021, we also intend to finish the calculations of the fundamental parameters (ionization cross-sections and emission yields) for Au and compare the impact of these new data in microdosimetric simulations. For this, we will propose a Master thesis theme in this topic.

3d-DoSkin/PRISM project

The 3d-DoSkin project was rebranded to PRISM (Proton Radiation Effects in Skin at the Microscale) project. Despite the lack of funding, we will continue the first task (detector development and optimization) using available resources at LOMaC, e-CRLab, and FCUL. This is the task related to the design and construction of the detector, including assembly and alignment of the fibers in a two-dimensional array, metrology solutions for checking the alignment of the fibres, routing, and connection to the MAPMT, readout electronics, and studies of the array response, including crosstalk effects. However, the remaining tasks of the project that were foreseen to be carried out by the bioengineering team in 2021, including cell and 3D reconstructed skin growth (on top of the fibers), are now seriously compromised due to the lack of financing. However, we intend to resubmit the PRISM project proposal in the 2021 IC&DT financing program of FCT but reinforcing the internationalization component by bringing in MD Anderson Cancer Centre (MDACC) researchers as consultants to the project.

Collaboration with the German Cancer Research Center (DKFZ)

The collaboration with João Seco, Professor and Divison Head of BioMedical Physics in Radiation Oncology at the German Cancer Research Center (DKFZ) and with the Medical Physics Research Graduate School of Heidelberg University is being put in practice with the co-supervision of PhD and Master theses. Students profit from the synergy between the radiation interaction simulation tools expertise existing at LIP and the extensive experience of João Seco in proton and carbon ion therapy. This line of work explores state-of-the-art developments in charged particle RT such as the potential curative effect of MBRT and of FLASH-RT.

Medium-term (3-5 years) prospects

The group's main objective in the coming years is to develop and deepen projects related to instrumentation for high-resolution dosimetry and microdosimetry. We intend that these projects reinforce the collaboration between LIP researchers and researchers in the field of bioengineering and cell biology. In this sense, the PRISM project is a solid proposal, so we would like to fully develop it. However, we are aware that success is very much dependent on the financing that we may or may not have.

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 to applications other than RT with NP, such as (proton) FLASH-RT and (proton) MBRT. 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 (initially through thesis projects) with other research centers, namely, HIT, DKFZ, Institut Curie/CNRS, and the UT MDACC.

We will continue to actively attract students to complete Master and PhD theses on these topics, taking advantage whenever possible of existing scholarship funding programs: individual FCT grants, PT-CERN and ProtoTera programs.

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. In the last year, it established collaborations with several medical and biology research institutions in Portugal (BioISI/FCUL, ITQB/ iNOVA4Health, C2TN/IST, and ICNAS/UC). It will also establishe collaboration with international research centers (DKFZ, Institut Curie/CNRS, MDACC/UT Austin).

Weaknesses

The number of FTE investigators is still small but has the potential to grow. The contractual situation of the group's researchers is in most cases precarious (including the group coordinator). There is no consolidated budget to guarantee medium-term research projects.

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, Institut Curie/CNRS, MDACC/UT Austin).

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 other research centers. It also limits the material support to the ongoing and future doctoral projects.

Dosimetry

Publications

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

- *"Structure of Kα1,2- and Kβ1,3-emission x-ray spectra for Se, Y, and Zr"*, Y. Ito, T. Tochio, M. Yamashita, S. Fukushima, A. M. Vlaicu, J. P. Marques, J. M. Sampaio, M. Guerra, J. P. Santos, Ł. Syrocki, K. Słabkowska, E. Węder, M. Polasik, J. Rzadkiewicz, P. Indelicato, Y. Ménesguen, M.-Ch. Lépy, and F. Parente, Physical Review A 102, 052820

Presentations

1 Presentation(s) in national conference(s)

- Patrícia Gonçalves: *"Protões em Portugal: as partículas na terapia do cancro"*, 2020-09-03, Física 2020 - 22ª Conferência Nacional de Física - Sociedade Portuguesa de Física, Lisboa

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

- Jorge Sampaio: *"Particles against cancer"*, 2020-02-05, 5th Lisbon mini-school on particle and astroparticle physics, Caparica

1 Outreach seminar(s)

- Duarte Guerreiro: *"Micro-scintillating array for real-time sensitive dosimetry for proton therapy using 3D human skin model"*, 2020-10-28, Dia da Investigação, Faculdade de Ciência da Universidade de Lisboa

Theses

3 PhD

- Dalila Mateus: *"Estudos dosimétricos para SBRT/SRT de pequenas lesões do Cérebro"*, (ongoing)
- Duarte Guerreiro: *"Scintillating array for real-time high-resolution ion therapy dosimetry"*, 2020-09-01 , (ongoing)
- José Miguel Venâncio: *"Bragg Peak monitoring through prompt-gamma: detection and instrumentation"*, 2020-09-01, (ongoing)

4 Master

- Joana Antunes: *"Simulations of radiosensitization efficacy of nanoparticles in proton therapy"*, 2020-11-24, (finished)
- 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)
- Nísia Fernandes: *"Estudo da radiossensibilização de células tumorais do pâncreas com nanopartículas"*, 2020-11-05, (ongoing)

[Radiation environment studies and applications for space missions]

Space Rad

i-Astro

RESEARCH / RADIATION ENVIRONMENT STUDIES AND APPLICATIONS FOR SPACE MISSIONS

SPACE RAD

Space Radiation Environment and Effects

Principal Investigator:
Patrícia Gonçalves (72)

6 ***Researcher(s):***
Alessandro de Angelis (2), Bernardo Tomé (10), Jorge Sampaio (35), Luisa Arruda (40), Marco Alves Pinto (90), Pedro Assis (10)

1 ***Master Student(s):***
Luís Sintra (49)

7 ***Trainee(s):***
Ana Maria Ribeiro, Bruno Marques, Cláudia Espinha, Filipa Baltazar, João Loureiro, Nuno Taborda, Pedro Lopes

1 ***External collaborator(s):***
Elsa Susana Fonseca

Total FTE:
3.1

Articles in international journals:	**2** Direct contribution **1** Indirect contribution
Internal notes:	**1** Collaboration note
International conferences:	**3** Oral presentations **1** Poster **1** Proceeding
International meetings:	**2** Oral presentations **1** Poster
Advanced Training Events:	**5** Oral presentations
Seminars:	**2** Seminars **9** Outreach seminars

Executive summary

In the past 17 years, an area of research and development focused on the study of the different space radiation environments and of 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	Code	Amount	Dates	Description
Patrícia Gonçalves	ESA: 1-7560/13/NL/HB	300.000 €	2014-02-18 / 2020-12-31	RADEM proto-flight model

Total: 300.000 €

Space Rad

Overview

The key issues for 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 in future exploration missions through the exploitation of scientific data and development of new technologies and dedicated sensors.
2. Assess the effects of radiation 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 current group activities are the following:

RADEM - development of the RADiation hard Electron Monitor for the JUICE ESA mission to the Jovian system, with launch foreseen in 2022. RADEM is developed by a consortium of institutes and industry including LIP, Paul Scherrer Institute in Switzerland, EFACEC SA in Portugal and IDEAS in Norway. LIP has been working on the RADEM detector heads design, response, and calibration, on the radiation analysis, and on the TID testing of the RADEM custom made ASICS. We expect the Proton Flight Model calibration to take place in the first half of 2021. LIP is also contributing to the data pipeline that will provide high-level products to the scientific community.

AlphaSAT radiation Environment and Effects Facility (AEEF) - AlphaSAT is the largest ESA telecom satellite, in geostationary orbit (GEO) since July 2013. LIP has been collaborating with EFACEC SA and EVOLEO SA in three different contracts regarding this facility. LIP is responsible for the analysis of the in-flight MFS data, the AEEF particle spectrometer and radiation monitor and also of the CTTB, the AEEF Component Technology Test Bed, where EEE components are being tested in GEO radiation environment. Both contracts finished at the end of 2019. Valuable scientific data acquired during 5 years are available and are being analyzed. LIP is developing a new unfolding method to obtain the MFS measured fluxes using neural networks. LIP was also involved in the ground testing and preparation of the CTTB data analysis prior to the AlphaSat launch and more recently on the analysis of RADFET in-flight measured doses and SEE rates detected by the SEU and SEL monitors.

Mars Energetic Radiation Environment Model - In 2008-2009 LIP has developed a model for the radiation Environment in Mars, dMEREM (detailed Martian Energetic Radiation Environment Model) in the framework of the MarsREM, the Martian Radiation Environment Models contract between ESA and an international consortium. dMEREM was interfaced with SPENVIS, the Space Environment Information System, where it is available to the community. Since then the capabilities of dMEREM have been exploited at LIP, and the model was the basis of several Master Theses. The ongoing work in this subject consists on the validation of the upgrade of dMEREM with data from Mars Curiosity Rover radiation detector (RAD). The validated model upgrade is being used in assessing radiation hazards for future manned missions to Mars and also for astrobiology studies.

The team is organized so that senior members take the responsibility of specific subjects and supervise PhD and Master students working in those subjects. Luisa Arruda is in charge of the MFS data analysis. She is also responsible for dMEREM update and its validation with data from RAD. Jorge Sampaio is responsible for the CTTB data analysis together with Marco Pinto. Marco Pinto is also responsible for RADEM flight model development and for the Radiation tests related to it. Pedro Assis supports the team in the activities requiring the collaboration with the e-CRLab. Patrícia Gonçalves coordinates the Group and is the supervisor of postgraduate theses at IST.

Assessment of the past year: objectives vs. achievements

- **The RADEM** contract was ongoing and the beam tests and calibration of its Flight Model that were scheduled to October 2020 are delayed to March 2021. The group continued following 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, as expected.
- **The MFS and CTTB Data Analysis** contracts are terminated because AEEF, designed for a 3 years mission, did not recover from a failure during the last semester of 2019. 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 several results were submitted to conferences or are being prepared for publication:
    - Very interesting correlations of CTTB data with solar activity were presented at RADECS2020 and a paper submitted. 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 defined 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. 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 than flew on the CTTB is finalised and will be submitted to publication. This study, where the the performance of the GaN components was analysed as a function of the the Total Ionizing Dose measured by the GaN board RADFET, was done in collaboration with researchers of Instituto de Telecomunicações at Universidade de Aveiro, responsible for the GaN experiment aboard the CTTB.
- A new unfolding method for the MFS measured fluxes was expected to be developed by Luís Sintra in his Master thesis work, which was discontinued. This work is fundamental for the MFS data analysis and also for the future BERM and RADEM data analysis will be continued and proposed for new Master theses opportunities.

- The activities concerning the exploration of the **GEANT4** based **Mars Radiation Environment Model** continued. On one side the validation of the Mars model with real data from RAD monitor at Mars surface was carried for two periods. Two different cosmic ray propagation models in the heliosphere were used as an input of dMEREM. The results will be submitted to a peer-reviewed publication.

Co-organization of the S^3 Space Seminar Series at IST together with Rodrigo Ventura (ISR-Lisboa, DEEC, IST), Zita Martins (CQE, DEQ, IST) and Paulo Gil (IDMEC, DEM, IST). The Space Seminar Series (S3) was planned to be a monthly multi-disciplinary seminar series at Instituto Superior Técnico, open to everybody, including students, researchers and staff members interested in space sciences and technology. There were three seminars planned for the 2nd semester of 2019/2020, postponed due to the lockdown. The Speakers were Chiara Manfletti, the President of Portugal Space (March), Eamonn Daly, former head of the Space Environments and Effects Section at European Space Agency (April) and David Wettergreen, Research Professor at Carnegie Mellon University (May). The seminars are expected to be resumed in 2021.

Luís Sintra discontinued his Master thesis work during the 1st semester of 2020, during the lockdown.

The Space group participated in the LIP Internship program. One student, Nuno Taborda, was selected to work on "Functional test studies for the Engineering Qualification Model of RADEM, the radiation monitor for the ESA JUICE mission, using Monte Carlo analysis". This internship allowed the student to learn about the Space radiation environment, radiation interaction with matter, programming, and data analysis, while working on a real-case problem. The results of the internship will be used in RADEM's environmental qualification.

Envisaged activities

Several proposals were prepared for 2020 calls.

- **Proposals to the FCT call for projects in all scientific domains (PTDC)**
  - **MarsRAD – The Mars radiation environment framework in support of Human exploration of Mars and astrobiology studies:** The proposal is based on the Mars radiation environment predictions of dMEREM and on the results obtained from the comparison of the model with the Radiation Assessment Detector (RAD) on the Curiosity rover that currently explores the surface of the planet. it was proposed to use the model to determine dosimetric quantities in female and male phantoms in order to derive relations between the radiation dose at the surface of the planet and the gender-dependent radiological risks. Dose calculations on astronauts were proposed to be extended to Earth outbound phase and cruise phase for possible trajectories to Mars to obtain an estimate of the radiological risk on complete missions. The project included subsurface predictions, which could be applied to astrobiology studies. The proposal was eligible for funding, but it was not selected (Overall Rating: 7.15/9).
  - **RadBioCube - Development of a miniaturized system concept to measure radiation and its effects biosignatures in Space:** The project was proposed in collaboration with Zita Martins from Centre of Structural Chemistry of Instituto superior Técnico (CQE/IST) and with SpinWorks, a Portuguese SME. The objective was to study a small instrument capable of measuring both radiation and radiation effects on biosignatures. The approach was to evaluate the appropriate radiation quantities to characterize radiation effects biosignatures using ground stations. Since experimental facilities at the Earth cannot reproduce the Space environment, the results would drive the development of a radiation detector to monitor deep Space biological experiments. The instrument was to be designed compatible with typical small satellite systems in order to facilitate flight opportunities. While the proposal was considered eligible for funding and had a very positive review from the evaluation panel, it was not selected (Overall Rating: 7.60/9).

- **Proposals to H2020 programme**
  - ***"UNFOLD"* proposal to the "Scientific Data Exploitation"**

    SPACE-30-SCI-2020 call : The proposal addressed the problem of data unfolding for particle data collected by the Galileo and Cassini missions , which would enable to attain a better understanding on the properties of energetic particle spectra, particularly in the MeV range, surrounding the gas giants. This project would provide valuable input for the preparation of the RADEM in-data analysis campaign. This proposal involved scientists at the Max Plank institute, at the University of Athens and at SPARC, a Greek PME. It was not selected for funding although it was classified above threshold (Overall Rating: 11/15).

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 continue the activities in which it is involved:

- **The RADEM** contract is ongoing and the beam tests and calibration of its Flight Model are scheduled to March 2021. 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.
- **The MFS and CTTB Data Analysis** 5 years of scientific data are available to be analysed. For the next year, we expect to consolidate the results of CTTB analysis, and to develop a method to calculate the Solar modulation factor with the SEU and SEL monitors. A new unfolding method for the MFS measured fluxes still need to be developed. MFS scientific data will be extensively analysed. Radiation effects on the CTTB components during the five years of data collection will continue to be studied.
- The activities concerning the exploration of the **GEANT4** based **Mars Radiation Environment Model** will continue. The validation of the Mars model with real data will be published on and Martian the underground radiation environment will be studies to predict possible existence of conditions for simple life forms. All studies will aim at predicting the effect of the energetic particle radiation in manned missions to Mars. Human phantoms will be used the simulation of flight and surface scenarios. This line of work is also bridging with the activities of the Dosimetry group. On the other hand, we will start to explore dMEREM assesment of Mars underground radiation environment to understand the potential of muon tomography studies in Mars. This is developed with straight connection with MuTom group.
- The strategy used in the development of the Martian Radiation environment Model is the basis for the development of a Lunar Radiation Environment model, whose preliminary studies and data assessment have already started in the context of the preparation of several proposals.

Proposals prepared

The group prepared several activities/calls/projects whose approval should be known during 2021 or that will be starting in 2021:

- **Analysis of the BERM radiation monitor in the BepiColombo mission -** BepiColombo is Europe's first mission to Mercury that was launched on October 20th 2018. The journey to Mercury will take about seven years and the spacecraft will enter the orbit around Mercury by end of 2025. BepiColombo consists of two spacecrafts, the Mercury Planetary Orbiter (MPO) provided by ESA and the Mercury Magnetospheric Orbiter (MMO) provided by JAXA. The MPO carries the BepiColombo Radiation Monitor (BERM) designed to measure electrons, protons and ions near the spacecraft. BERM was built by EFACEC and IDEAS. LIP now joins the effort to check validate the first data. LIP will be co-responsible with PSI for in-flight data validation, cross-calibration of BERM with the SIXS instrument, and for developing high-level products. The kick-off meeting for this contract is planed for March 2021.
- **Low Cost radiation Monitor -** In 2020, EFACEC, IDEAS, LIP and SE2S, established an agreement for design, development, manufacturing, integration and test a prototype of a Low-Cost Radiation Monitor (LCRM) as a request from PT Space Agency. The aim of this prototype is to validate the concept in order to start having the LCRM onboard of "all i.e. as many as possible" satellites giving the scientific community reliable and statistically more significant data to improve our models and, in this way, minimise risk and cost on future missions and other space and on-ground activities. EFACEC will be the prime contract for LCRM with partners from Portugal (LIP), Switzerland (SE2S) and Norway (IDEAS). The goal at the end of the LCRM project is to have a "product" that can be reused "as is". Two-three typical orbits as well as physical concepts are foreseen to be defined. The proposal was submitted to PT Space and ESA and the outcome is awaited.

- **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", lead by Dr. Peter WEISS, Head of the Space Department in COMEX (a French company with large experience in the development of technologies for human intervention in extreme environments) and in collaboration with CIRiS (Centre for Interdisciplinary Research in Space), from the Norwegian University of Science and Technology. The proposal is currently in the Evaluation phase and results are expected in 2021.

Proposals in preparation

The group is currently preparing for the following activities/calls /projects :

- **Proposals to the FCT call for projects in all scientific domains (PTDC)**
  - A project to the "Scientific Research Projects and Technological Development (IC&DT)" call based on planetary radiation environment predictions and radiation environment modelling for human space flight, on the follow up of the project submitted in 2020 to the FCT PTDC call is under preparation.

Collaborative activities

With other LIP research groups

During 2019, it was confirmed that Portugal will have a centre for proton therapy at the Nuclear and Technological Campus of IST expected to be operating in 2024, that will be also used for research purposes fostering an interdisciplinary network to further develop applications and projects in the field of space radiation environment. LIP is a founder member of the ProtoTera Association created in December 2019 to promote the development of a national research network in advanced therapies and associated technologies to treat cancer patients. The SpaceRad group has been collaborating in LIP´s efforts to put together an R&D strategy to support this interdisciplinary network. In this context, the group has been collaborating with the LIP Dosimetry and OR Imaging groups. This collaboration has been centred on the development of microdosimeters aimed at supporting proton therapy, but that can also be used for measuring the effects of cosmic rays at cellular level: the idea of this collaboration is to explore the use of these devices for human spaceflight, for the study of the effects of high LET ions in the crews.

At Instituto Superior Técnico

A Minor in “Space Sciences and Technologies” was approved at Instituto Superior Técnico and related to it a series of “Space Seminars” is being organized. Patrícia Gonçalves was involved in the proposal for a "Minor", which will start in 2021. Patrícia Gonçalves has also been actively involved in the team that is organizing the “Space Seminar Series” (S^3), which were planed for 2020, but are expected to start in 2021.

With “Agência Espacial Portuguesa”, PT-Space

The Portuguese Space Agency, PT-Space, which was created in 2019, was recently invited to join the NASA “International Space Exploration Coordination Group” (ISECG) and there was a (very) small increase in the budget for the Portuguese participation in the ESA Exploration programme after the November 2019 ESA ministerial meeting. In this context, an informal group of experts of which Patrícia Gonçalves is a member, has been in contact with PT-Space on this subject.

Several Master thesis subjects were announced for Engineering Physics students ate IST and to Physics and Engineering Physics students at FCUL. Several PhD thesis proposals were announced at PT Space call for PhD grants in January 2021.

Medium-term (3-5 years) prospects

For the period, from 2024 to 2027, the Group aims to:

- Be involved in the next phases of the **RADEM detector development, testing and deployment** and also the scientific team of the JUICE mission to the Jovian system, in the area of energetic particle radiation environment and effects.
- Explore the potential of **RADEM data** collected during the cruise phase. In the first case the data will contribute to a better understanding of the heliospheric radiation environment.
- Join the BepiColombo science team and explore the potential of **BERM data** collected and correlate this set of data with the other radiation monitor data in other heliospheric points. LIP joins 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.
- 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 the Portuguese Space Agency, 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

- 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. Expertise in GEANT4-DNA is going to be acquired in order to access the radiation effects on biological systems.
- 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.
- The team senior members have a wide experience in participating in international scientific collaborations since the beginning of their scientific careers.
- Some senior members are deeply involved with academia which facilitates the attraction of new students for the group providing a strong training plataform.

Opportunities

- Collaboration with industry, Contracts with European Space Agency
- Participation in consortia for H2020 calls and oter international funding programmes
- Participation in scientific consortia or teams for future space missions to enhance the scientific component of the activity
- The group has embraced several outreach activities to disseminate its potential activity to Physics students both from University and from High School.
- Collaboration with other LIP groups in common or in complementary subjects
- Interdisciplinary collaboration at the Universities in Space Science and Technologies projects
- Connection and networking with Portuguese community in Space for science and exploration.

Weaknesses

- In terms of funding the group heavily depends on contracts with the European Space Agency with a typical duration between 1 year to 3 years. The last contract finished during 2020. No funding obtained in last FCT call for projects.
- Students' learning curve has a mild slope and it is therefore difficult to articulate with the average duration of the contracts, in the case where they are developing academic work in the framework of a contract subject.
- Several attractive opportunities to trained students after obtaining postgraduate or undergraduate studies from industry in and outside Portugal
- Difficulty in attracting trained researchers in the area due to budgetary and career development constraints

Threats

- National project calls have been unpredictable both in what concerns rules in each call, publication of results and replies to requests of review.
- The proposals to national project calls by the Portuguese funding agency (FCT) have been submitted to the Physics panel, which does not usually have members who know the area of Space Applications. There is no specific evaluation panel for Space exploration or space science.
- Timing and duration of the contracts: since the average duration of the contracts with ESA is under 2 years, there can be several of these contracts overlapping in time, which demands too much manpower or possible periods with no founding.
  - Work from different and simultaneous contracts may have 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.
- Constant networking effort and attention to ESA intended and published invitation to tender calls is required as well as to H2020 opportunities or others.
- To plan for this activity as a service oriented activity only, when the scientific potential can be exploited.
- Current pandemic situation difficults the contact with students, affecting the student attraction potential for Master and PhD theses.

Space Rad

Publications

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

- *"Beam test results of a prototype of the Radiation Hard Electron Monitor to be flown in the JUICE mission"*, P. Socha, M. Pinto, W. Hajdas and P. Gonçalves, Journal of Instrumentation, Volume 15, June 2020 IPRD19
- *"Dose Measurements and Simulations of the RADFETs Response Onboard the Alphasat CTTB Experiments"*, J. M. Sampaio, M. Pinto, P. Gonçalves et al., IEEE Transactions on Nuclear Science, vol. 67, no. 9, pp. 2028-2033, Sept. 2020

1 International Conference Proceedings

- *"The RADiation hard Electron Monitor (RADEM) for the JUICE mission"*, M. Pinto, P. Gonçalves et al., Europlanet Science Congress 2020, online, 21 September–9 Oct 2020, EPSC2020-311, 2020

1 Collaboration note(s) with internal referee

- *""RADEM Cs-137 Source functional test GEANT4 simulation"*, M. Pinto, P. Gonçalves et al., Technical Note (26/04/2020)

Presentations

3 Oral presentations in international conferences

- Marco Alves Pinto: *""CTTB Memory Test Board Single Event Effect Geostationary In-flight Data Analysis" "*, 2020-09-21, RADECS 2020 online, Online
- Marco Alves Pinto: *"The RADiation hard Electron Monitor (RADEM) for the JUICE mission"*, 2020-09-25, Europlanet Science Congress 2020, Online
- Marco Alves Pinto: *"The RADiation hard Electron Monitor (RADEM) for the JUICE mission"*, 2020-12-01, SpaceMON 2020, online

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

- Marco Alves Pinto: *"The RADiation hard Electron Monitor (RADEM) for the JUICE mission"*, 2020-11-05, Outer planet moon - magnetosphere interaction workshop - Virtual Meeting, Online

2 Oral presentations in national or international meetings

- Luisa Arruda: *"Space Rad Activities at LIP"*, 2020-02-16, Jornadas Científicas LIP 2020, Universidade do Minho, Braga
- Marco Alves Pinto: *" Space Rad activities at LIP"*, 2020-02-16, Jornadas Científicas LIP 2020, Universidade do Minho, Braga, Universidade do Minho, Braga

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

- Luís Sintra: *"Particle Energy Spectra Reconstruction of the MFS Data using Machine Learning Techniques"*, 2020-02-15, Jornadas Científicas LIP 2020, Universidade do Minho, Braga

5 Oral presentations in advanced training events

- Patrícia Gonçalves: *"From Particle Physics to Space & also to ... Health Applications"*, 2020-02-07, Fifth Lisbon mini-school on Particle and Astroparticle Physics, Costa da Caparica
- Patrícia Gonçalves: *"From Particle Physics to Space and also to ... HEALTH Applications"*, 2020-02-07, Fifth Lisbon mini school on Particle and Astroparticle Physics, Laboratorio de Instrumentação e Física Experimental de Partículas (Costa da Caparica , Portugal)
- Patrícia Gonçalves: *"Sensitve Volumes in GEANT4"*, 2020-02-13, LIP Introductory course on GEANT4, Laboratorio de Instrumentação e Física Experimental de Partículas (Braga, Portugal)
- Nuno Taborda: *"Functional test studies for the Engineering Qualification Model of RADEM, the radiation monitor for the ESA JUICE mission, using Monte Carlo analysis"*, 2020-09-10, LIP Intership Program Workshop, LIP Lisboa
- Patrícia Gonçalves: *"Radiation Environment in Space.: a showstopper for human exploration of the solar system?"*, 2020-09-17, Verão com Ciência | Escola de Verão: Física Nuclear Aplicada, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa (Monte da Caparica, Portugal)

2 Seminars

- Patrícia Gonçalves: *"Modeling Planetary Radiation Environments in Preparation for Future Human Exploration Missions"*, 2020-10-14, Physics Department IST-Physics Department (Lisboa, Portugal), Physics Department IST- Physics Department (Lisboa, Portugal)
- Marco Alves Pinto: *"Space Radiation Environment and Effects: From Earth to Jupiter"*, 2020-10-28, Café com Física, Departamento de Física - Universidade de Coimbra

9 Outreach seminars

- Marco Alves Pinto: *"Para o espaço e mais além"*, 2020-01-13, O Espaço vai à Escola, Agrupamento de Escolas Gil Paes - Torres Novas
- Marco Alves Pinto: *"Para o espaço e mais além"*, 2020-10-06, O Espaço vai à Escola- ESERO, Escola EBI/JI Padre Joaquim Flores
- Marco Alves Pinto: *"Para o espaço e mais além"*, 2020-10-06, O Espaço vai à Escola- ESERO, EB Santa Marta do Pinhal - Corroios
- Marco Alves Pinto: *"Para o espaço e mais além"*, 2020-10-07, O Espaço vai à Escola- ESERO, EBI Santa Cruz da Trapa - Santa Cruz da Trapa
- Marco Alves Pinto: *"Para o espaço e mais além"*, 2020-10-07, O Espaço vai à Escola- ESERO, EB23 Abação - Guimarães
- Luisa Arruda: *"Para o Infinito e mais além em segurança! (sempre que possível...)"*, 2020-10-07, O Espaço vai à Escola- ESERO, Agrupamento de escolas do Algueirão
- Marco Alves Pinto: *"A bordo da Missão JUICE"*, 2020-10-14, O Espaço vai à Escola- ESERO, Agrupamento de Escolas de Nisa - Nisa
- Marco Alves Pinto: *"A bordo da Missão JUICE"*, 2020-10-15, O Espaço vai à Escola- ESERO, Escola Básica e Secundária da Madalena - Ilha do Pico
- Luisa Arruda: *"Para o Infinito e mais além em segurança! (sempre que possível...)"*, 2020-10-15, O Espaço vai à Escola- ESERO, Escola Secundária Maria Amália Vaz de Carvalho, Lisboa

I-ASTRO

Space Instrumentation for Astrophysics

Principal Investigator:
Rui Curado Silva (85)

9 ***Researcher(s):***
Alessandro de Angelis (5), André Cortez (5), Filipa Borges (15), Filomena Santos (10), Jorge Maia (45), José Escada (20), Marco Alves Pinto (10), Miguel Moita (100), Teresa Dias (15)

1 ***PhD Student(s):***
Alexandre Fonseca Trindade (30)

3 ***Master Student(s):***
Gabriel Salgado (100), Henrique Neves (100), Joana Mingacho (100)

1 ***Undergraduated Students:***
Giorgio Canezin

Total FTE:
6.5

International conferences:	**2** Posters
	1 Proceeding
National conferences:	**1** Oral presentation
	1 Poster
International meetings:	**2** Oral presentations
Seminars:	**8** Outreach seminars
Completed theses:	**1** PhD
	1 Master

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 astrophysics. The group is part of AHEAD2020 (Activities in the High Energy Astrophysics Domain) EU project as well as of NASA AMEGO (All-sky Medium Energy Gamma-ray Observatory) mission proposal consortium. Furthermore, we are leading two ESA calls' projects: "Ageing of Ge/Si and CZT samples for sensors and Laue lenses" experiment onboard the International Space Station (ISS) and BEXUS STRATOSpheric POLarimetry with Cadmium Telluride Array (STRATOSPOLCA) experiment. Our group is contributing to the development of detection plane space instruments based in CdTe, CZT, CsI, Si and in gas-filled detectors, with polarimetric capabilities. Polarimetry in high-energy astrophysics has known very few developments, however it holds a vast potential to open a new scientific observational window.

The new AHEAD2020 EU funded project started in March 2020 and our group takes part in Work Package 11 (WP11) "Space Experiments for HE Astrophysics & Multi-messenger Astronomy" activities developing a compact Compton Telescope (`COMCUBE') prototype, CubeSat-compatible, that offers game-changing GRB polarimetric capability in the few hundred keV range. Simulations of several possible designs were performed, the respective results were analyzed and discussed during the Coimbra AHEAD2020 Progress Meeting on Space Experiments for HE Astrophysics & Multi-messenger Astronomy, organized remotely by LIP in October 2020. The STRATOSPOLCA flight model was developed, the detector and electronics were integrated and tested at LIP laboratories.

Research activities concerning 2020 ProtonRadCdTe (Protons Radiation Hardness in CdTe Detectors for Space Instrumentation) research evolved to an experiment ("Ageing of Ge/Si and CZT samples for sensors and Laue lenses") onboard the ISS, that was successfully selected in an ESA Euro Material Ageing competitive call. This experiment is led by LIP, in collaboration with University of Beira Interior (UBI), INAF, University of Ferrara (UF), Active Space and Istituto dei Materiali per l'Elettronica e il Magnetismo (IMEM), Parma. This research line aims to characterize the effects of orbit proton radiation environment on CdTe based instrument in the context of a Low-Earth Orbit (LEO) mission: i) the damage effects on the CdTe crystals and the deterioration of the detectors operational performance, ii) the nuclear activation in CdTe material and the gamma-ray background noise. The present study is important in the framework of the development of a CdTe instrument for a medium-energy gamma-ray observatory, anticipating the possibility of future short- to long-duration LEO mission, up to ~20 years.

Also, we kept contributing to the development of the main instrument of a future X-ray polarimetry mission, with energy within 2-20 keV, by simulating the Gas Pixel Detector (GPD) potential polarimetric performance for different noble gases: Xe, Ar, Ne and He, and their mixtures with molecular gases.

Sources of funding

PI	Code	Amount	Dates	Description
Rui Curado Silva	654215 - AHEAD	61.225 €	2015-09-02 / 2024-03-01	Integrated Activities for the High Energy Astrophysics Domain
Rui Curado Silva	871158-AHEAD 2020	30.000 €	2020-03-02 / 2024-03-01	Integrated Activities for the High Energ...

Total: 91.225 €

i-Astro

Overview

Development of spectro-imagers with polarimetric capabilities for high-energy astrophysics has been progressing. Our research activities are divided in three lines of work: 1) AHEAD project; 2) ProtonRadCdTe project; 3) Gaseous detectors for astrophysics.

1- In AHEAD2020 our group will contribute to COMCUBE demonstrator and AMEGO mission developments (R. da Silva coordinates the participation in both projects).

1.1- In the framework of WP11, for the period of 2020 we coordinated the simulation task, developing and delivering the first version of COMCUBE demonstrator design. The detector simulation is part of Henrique Neves' Master thesis under the supervision of J. Maia and R. da Silva.

1.2- In order to optimize the AMEGO mission design and validate the instrument missions' performances, our group will participate in the instrument simulations as well as in the prototype testing, to be performed by students G. Salgado and G. Canezin, under the supervision of R. da Silva and F. Santos. Prototype development in the USA was delayed about one year due to COVID-19.

2- The ProtonRadCdTe project, with the goal of evaluating the proton radiation hardness in CdTe detectors in context of a LEO mission, evolved to ESA Euro Material Ageing experiment onboard ISS under the coordination of J. Maia. Led by LIP, the experiment is a collaboration with UBI, INAF, UF, Active Space and IMEM. A set of crystals for high-energy astrophysics instrumentation will be tested on the ISS orbit environment with the goal to study its effects on the detectors' performances, by analyzing its response before and after the flight. The launch to the ISS is scheduled to July 2022.

3- The development of focal plane instruments for X-ray polarimetry in astrophysics based on Gas Pixel Detector (GPD) X-ray polarimeter is being set in collaboration with the Gran Sasso Science Institute (GSSI). GPD gas mixture study is being developed by J. Escada and A. Trindade, supervised by R. da Silva and J. Maia.

3.1- GPD gas mixture simulations are being performed by J. Escada, with the collaboration of J. Maia and R. da Silva.

3.2- GPD gas mixture testing is being performed by A. Trindade under the supervision of F. Santos and J. Maia.

Assessment of the past year: objectives vs. achievements

The objectives for the past year were divided in three lines of work: 1) AHEAD; 2) ProtonRadCdTe project; 3) Gaseous detectors for astrophysics:

1- The new AHEAD2020 project started in March 2020. AHEAD WP11 activities will focus in a COMCUBE demonstrator and will also support our participation in the ESA BEXUS program and on the AMEGO NASA proposal.

1.1 – i-Astro LIP group led the AHEAD2020 WP11 COMCUBE simulation task, which was concluded in October 2020 and whose objectives were successfully attained. In the online international meeting "Coimbra AHEAD2020 Progress Meeting on Space Experiments for HE Astrophysics & Multi-messenger Astronomy" was presented the final design that arose from the mass model simulations. This design consists of an instrument based on a DSSD (double-sided silicon strip detector) tracker and a set of calorimeter scintillator detectors that meet the volume, mass and power budget of a 4U nanosatellite, as well as the scientific objective of measuring at least 10 GRB per year, including its polarization (two communications were presented at this international meeting; one paper was published in international conference proceedings; three articles were submitted to international journals).

1.2 – In the framework of the AMEGO proposal development, i-Astro is contributing to mass model simulations with the MEGAlib simulation toolkit for a small size prototype experiment that was scheduled to be tested at the Duke University beamline, where our group should coordinate the polarization testing. Unfortunately, due to COVID-19, the prototype integration and testing was delayed by one year. Furthermore, we developed a simulation model to estimate AMEGO-X mission proposal polarimetric performance for the Science Review Meeting of NASA MIDEX call for missions (deadline in 2021).

1.3 – The STRATOSPOLCA experiment should have been launched in an ESA BEXUS program balloon platform from Kiruna, Sweden, in October 2020. However, due to COVID-19, the launched was delayed to October 2021. Nevertheless the STRATOSPOLCA detector was integrated with the electronic system and preliminary tests performed.

2- In the ProtonRadCdTe research line, the ESA Euro Material Ageing call provide us an excellent opportunity to step our research work from the ICNAS cyclotron beam orbit proton analogue tests to the real orbit environment onboard the Bartolomeo platform. Our proposal was selected among 15 out of 47. Furthermore, Portugal Space will fund our experiment via the PRODEX funding line at the level of ~120 k€ for 3 years (including one year flight). Therefore, our expectations for 2020 and subsequent years were largely exceeded.

3- In this research line, the collaboration framework was changed from IXPE NASA mission consortium, that was not open to further European partners (NASA IXPE mission is based on the XIPE ESA pre-selected mission leaded by INAF Roma, where we were partners). The development of focal plane instrument for X-ray polarimetry in astrophysics based on GPD X-ray polarimeter is now being set in collaboration with the Gran Sasso Science Institute (GSSI).

Several GPD gases mixtures were simulated with a in-house developed Monte-Carlo code and analyzed. The sensitivity to X-ray polarization of noble gases (He, Ne, Ar, Xe), CH4, and of mixtures between a noble gas and CH4 was calculated.

An upgrade of our code implemented more realistic conditions, such as determining the modulation factor in gas detector through the reconstruction of photoelectron emission direction, instead of the entire electron cloud, and also accounts for the effect of electron transversal diffusion towards the anode readout.

The objective of setting-up the experimental system to measure electron transversal diffusion was achieved and the first measurements were performed with success for Xe. The data is being analyzed to compare them with the literature, in order to fine-tune the measurement methodology and move towards molecular gases (CH4, DME) and mixtures between noble gases and molecular gases.

Advanced training is an important part of the group's activities (see list of PhD and Master theses).

Lines of work and objectives for next year

The objectives of the main lines of work, 1) AHEAD, 2) ProtonRadCdTe and 3) Gaseous detectors for astrophysics, for 2021 are:

1- The new AHEAD2020 will enter the second year out of four. 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. Afterwards, further prototype development is envisaged in order to set a balloon born prototype testing, at ~40 km, that will likely take place in 2022.

1.3 – The STRATOSPOLCA experiment will be launched in an ESA BEXUS program balloon platform from Kiruna, Sweden by October 2021, after one year delay due to COVID-19. Its objectives are:

i- Measure the level of double-events' background, as well as the level of single events and of 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 measured results with those obtained when simulating a balloon flight in similar conditions with the polarimetry MEGAlib simulation code, developed by the student's Simulation Team, in order to validate this code and its analysis methods;

2- In ProtonRadCdTe research line we will perform Euro Material Ageing project tasks for 2021. In collaboration with IMEM), a set of 10 CZT detector similar samples will be produced. Afterwards, we will perform safety tests to comply with ISS safety standards. In order to assess accurately the CZT detector crystals degradation after the flight under ISS orbit environment, scientific performance tests with 5 CZT crystals will be performed, throughout 2021. At this point, a new methodology to monitor the displacement damage coefficients caused by proton radiation will be introduced and developed: a methodology based in the analysis of current and charge pulses of CZT detectors. The remaining 5 CZT samples will be delivered to ESA by September 2021. The launch of the samples to the ISS will take place in July 2022.

3- In the Gaseous Detectors for Astrophysics research line, in collaboration with GSSI, our group has the task to assess the best trade-off gas mixture, between the sensitivity to X-ray polarization and the detection efficiency. The upgrade of our code will be completed to accomplish more realistic conditions in the simulations, namely the reconstruction of photoelectron emission direction and the effect of electron transversal diffusion towards the anode readout. The sensitivity to X-ray polarization of noble gases (He, Ne, Ar, Xe), CH4, DME and mixtures of a noble gas and a molecular additive (CH4, DME) will be calculated.

Further experimental measurements will be performed in order to measure electron transverse diffusion in molecular gases (CH4, DME) and mixtures of a noble gas and a molecular additive (CH4, DME), and the results will be compared with simulations.

Medium-Term (3-5 years) prospects

The i-Astro 2021-2026 research plan consists on developing innovative concepts in order build optimised space instruments for the orbital environment and for high-energy astrophysics, in the framework of future mission proposals such as AMEGO or COMCUBE.
In AHEAD2020, we expect to 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 a CubeSat constellation, allowing for performant high-energy astrophysics experiments 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 CZT Euro Material Ageing 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 precious guidelines for future high-energy gamma-ray telescopes design. Alternative materials will be proposed to 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 experiments on orbital radiation effects with detector crystals integrated in active mode onboard the Space Rider.

In collaboration with GSSI we will simulate, develop and test a gas-based prototype detector with optimised gas mixtures and electron multipliers based in GEMs for X-ray spectroscopy and polarimetry. The solution should be adopted for a novel CubeSat X-ray polarimeter nanosatellite platform, PolarLight, that will be the first photoelectric regime polarimeter that will operate in space, opening a new scientific window on the hard X-ray astrophysics domain.

SWOT Analysis

Strengths and Opportunities

i-Astro is leading the CZT Euro Material Ageing experiment international team 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 a 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 CZT ESA Euro Material Ageing experiment provides an outstanding opportunity, under ISS orbital environment, to estimate performance degradation at LEO, therefore providing precious guidelines for future high-energy gamma-ray telescope design.

Weaknesses and Threats

The level of collaboration with industry is still weak, however CZT Euro Material Ageing experiment will allow to collaborate in the security tests with Active Space company via PRODEX funding.

Last decade's lack of national funding has compromised seriously project funding, equipment acquisition, as well as the number of grants and contracts available for young and senior researchers, as the group PI.

i-Astro

Publications

1 International Conference Proceedings

- *"Monte Carlo study of a 3D CZT Spectroscopic-imager for Scattering Polarimetry"*, M. Moita, L. Ferro, E. Caroli, E. Virgilli, R. M. Curado da Silva, N. Auricchio, S. Del Sordo, J. M. Maia, J. Stephen , 2020 IEEE Nuclear Science Symposium and Medical Imaging Conference

Presentations

2 Poster presentations in international conferences

- Miguel Moita: *"Monte Carlo study of a 3D CZT Spectroscopic-imager for Scattering Polarimetry"*, 2020-11-03, 27th International Symposium On Room-temperature Semiconductor Detectors / IEEE NSS RTSD MIC Conference 2020, Boston, USA
- Miguel Moita: *"Polarimetric Potential of AMEGO-X Mission Proposal"*, 2020-11-04, 27th International Symposium On Room-temperature Semiconductor Detectors / IEEE NSS RTSD MIC Conference 2020, Boston, USA

2 Oral presentations in national or international meetings

- Miguel Moita: *"AMEGO-X polarimetric prospects"*, 2020-10-02, Coimbra AHEAD2020 Progress Meeting on Space Experiments for HE Astrophysics & Multi-messenger Astronomy, Departamento de Física, Universidade de Coimbra
- Rui Curado Silva: *"COMCUBE Part 3 "*, 2020-10-02, Coimbra AHEAD2020 Progress Meeting on Space Experiments for HE Astrophysics & Multi-messenger Astronomy, Departamento de Física, Universidade de Coimbra

1 Presentation(s) in national conference(s)

- Rui Curado Silva: *"STRATOSPOLCA: STRATOSpheric POLarimetry with Cadmium telluride Array"*, 2020-09-10, XXX Encontro Nacional de Astronomia e Astrofísica, Instituto de Astrofísica e Ciências do Espaço, Porto

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

- Miguel Moita: *"Polarimetric Potential of AMEGO-X Mission Proposal"*, 2020-09-10, XXX Encontro Nacional de Astronomia e Astrofísica, Instituto de Astrofísica e Ciências do Espaço, Porto

8 Outreach seminars

- Rui Curado Silva: *"Aquecimento Global - Consequências e Soluções"*, 2020-01-13, , Escola Secundária da Sé, Lamego
- Rui Curado Silva: *"Como Ser Astronauta"*, 2020-01-14, , Escola Secundária Domingos Sequeira, Leiria
- Rui Curado Silva: *"Portugal no Futuro da Exploração Espacial"*, 2020-06-26, Webinar STRATOSPOLCA, Departamento de Física, Universidade de Coimbra
- Rui Curado Silva: *"Como Ser Astronauta"*, 2020-10-06, , Agrupamento de Escolas de Penacova, Penacova
- Rui Curado Silva: *"Como Ser Astronauta"*, 2020-10-09, , Escola Conde de Arnoso, Arnoso Santa Maria
- Rui Curado Silva: *"Como Ser Astronauta"*, 2020-10-14, , EBS das Flores; Santa Cruz das Flores, Açores
- Rui Curado Silva: *"Como Ser Astronauta"*, 2020-10-21, , Agrupamento de Escolas Professor Abel Salazar; Guimarães
- Rui Curado Silva: *"Como Ser Astronauta"*, 2020-11-16, , Agrupamento de Escolas de Santa Comba Dão

Organized Events

1 Collaboration Meetings

- *"Coimbra AHEAD2020 Progress Meeting on Space Experiments for HE Astrophysics & Multi-messenger Astronomy"*, [Coll-Mtg] 2020-10-01 / 2020-10-02, Departamento de Física, Universidade de Coimbra

Theses

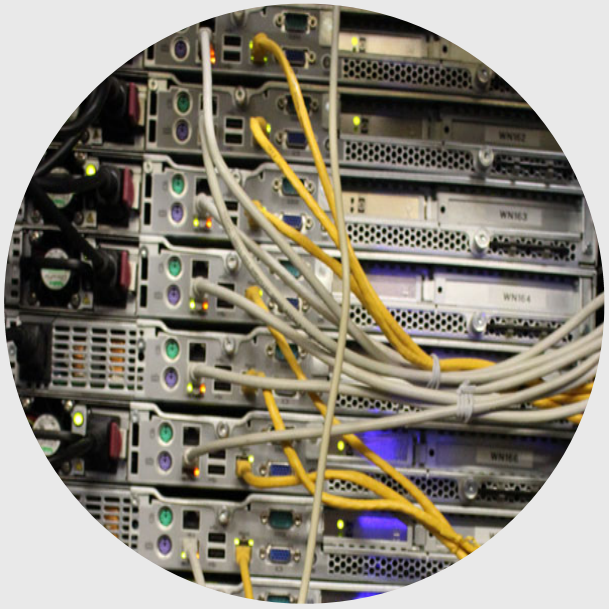
2 PhD

- Miguel Moita: *"ASTROGAM Space Gamma-ray Telescope Main Instrument Development"*, 2015-01-01 / 2020-02-21, (finished)
- Alexandre Fonseca Trindade: *"Study of noble gases mixtures characteristics as a detection medium"*, 2017-01-01 , (ongoing)

3 Master

- Joana Mingacho: *"Terrestrial Gamma-ray Flashes analysis for Aircraft Transport Safety"*, 2019-09-01 / 2020-11-26, (finished)
- Henrique Neves: *"Constelação de microssatélites para astrofísica multi-mensageira"*, 2020-09-01 , (ongoing)
- Gabriel Salgado: *"Polarimetria com protótipos Experimentais para a Missão AMEGO"*, 2020-09-01 , (ongoing)

Computing



[Scientific Computing]

GRID

Adv Comp

SPAC

GRID

Distributed Computing and Digital Infrastructures

Principal Investigator:
Jorge Gomes (100)

3 ***Researcher(s):***
João Paulo Martins (100), João Pina (100), Mário David (100)

8 ***Technician(s):***
Carlos Manuel (100), Dinis Monteiro (54), Henrique Carvalho (50), Hugo Gomes (100), José Aparício (100), Marta Castro (33), Nuno Ribeiro Dias (100), Samuel Bernardo (100)

6 ***External collaborator(s):***
André Vieira, Catarina Ortigão, Isabel Campos, João Machado, Miguel Viana, Zacarias Benta

Total FTE:
10.4

Articles in international journals:	**3** Direct contribution
Internal notes:	**12** Collaboration notes
International conferences:	**6** Oral presentations **1** Poster **3** Proceedings
National conferences:	**3** Oral presentations
International meetings:	**5** Oral presentations
Collaboration meetings:	**10** Oral presentations
Seminars:	**1** Seminar
Organized Events:	**1**

Executive summary

The LIP Distributed Computing and Digital Infrastructures Group provides information and communications technology (ICT) services to LIP. These services support research, innovation, education, outreach and administrative activities. 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). 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 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 current activities are focused on data processing using cloud computing, high throughput computing, high performance computing and machine learning. The group is currently participating in the H2020 projects EOSC-hub, EOSC-Synergy, EGI-ACE, EuroCC and C-Scale.

Based of the the accumulated experience the group is also delivering scientific computing services to the wider Portuguese scientific and academic communities in the context of the Portuguese National Distributed Computing Infrastructure (INCD), of which LIP is the main technological partner. The group is also engaged in national activities related to High Performance Computing (HPC) in the context of the national advanced computing network (RNCA).

The group activities bridge at international level with science related 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	Code	Amount	Dates	Description
Jorge Gomes	INCD 01/SAICT/2016 - nº 022153	223.000 €	2017-07-18 / 2021-07-17	Portuguese National Distributed Computing Infrastructure
Jorge Gomes	DEEP-HybridDataCloud - Grant 777435	362.500 €	2017-11-01 / 2020-04-30	Designing and Enabling E-Infrastructures for intensive Processing in a Hybrid DataCloud
Jorge Gomes	EOSC-hub grant 777536	338.687 €	2018-01-01 / 2021-03-31	Integrating and managing services for the European Open Science Cloud
Jorge Gomes	EOSC-synergy grant 857647	433.000 €	2019-09-01 / 2022-02-28	European Open Science Cloud – Expanding Capacities by Building Capabilities
Jorge Gomes	BigHPC 04/SI/2019	249.592 €	2020-03-01 / 2023-02-28	A Management Framework for Consolidated Big Data and HPC
Jorge Gomes	EUROCC	296.000 €	2020-09-01 / 2022-08-31	Innovating and Widening the HPC use and skills base
Jorge Gomes	EGI-ACE	196.238 €	2021-02-01 / 2023-08-31	Implementing the European Open Science Cloud
Jorge Gomes	EOSC-Future	219.000 €	2022-01-01 / 2024-12-31	EOSC-Future

Total: 2.318.017 €

GRID

Overview

The group activities are organized in four main areas:

- Scientific computing and data processing services, such as processing farms, cloud computing, data storage. Participation and liaison with international digital infrastructures and initiatives such as WLCG, EGI, IBERGRID and EOSC. The actual delivery of compute and data services is performed in the context of the Portuguese National Distributed Computing Infrastructure (INCD), whose activities have been pioneered by LIP. INCD is a digital infrastructure in the context of the FCT roadmap of research infrastructures of strategic interest.
- ICT R&D&I projects, enabling 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, software quality assurance and others.
- Core institutional services for LIP, including support to administrative services, network related services, desktops, laptops, security, authentication and authorization, printing services, data protection and others.
- Web services, web development, graphics design and multimedia services, aiming at supporting outreach, dissemination, exploitation, management and research activities.

The work in these areas is organized in a virtuous cycle. The research activities enable the evolution of the services and infrastructures delivered by the group, while the services and infrastructures themselves support the continued participation in research and innovation projects. The delivery of compute and data intensive services is performed on the wider context of INCD, including researchers, engineers and technicians from LIP complemented by staff from INCD acting under the group coordination.

Assessment of the past year: objectives vs. achievements

The group is responsible for the LIP core IT services and datacenter facilities. The IT processes were improved with the integration of the single sign-on (SSO) across the organization and the streamlining of common tasks through a management portal connected to the LIP institutional database. New collaboration and documentation tools for IT management were introduced. In terms of facilities the LIP Lisbon datacenter at 3Is became fully operational. The virtualization, web and network services were improved. The actual upgrade of the hardware is waiting for funding from the Associate Laboratory programme.

The LIP scientific computing capacity relies on services operated by LIP in partnership with INCD. LIP has been the main promoter of INCD, a multidisciplinary digital infrastructure established as a private non-profit association joining LIP, FCT and LNEC. LIP participates in the management bodies of the association, and is coordinating the infrastructure technical activities including development, operation and support. These activities are being funded by the Portuguese research infrastructures roadmap through a national project.

The INCD infrastructure has delivered more than 47 000 000 CPU hours of batch and cloud processing. The INCD center in the north, hosted by LIP Minho, is supporting HTC and HPC applications that exploit the Bob supercomputer under an agreement with FCT. LIP is managing the data storage systems for this supercomputer which is split in two partitions managed by INCD and MACC. The expertise gathered at this center is enabling a smoother migration of the INCD Lisbon batch system from SoGE to Slurm. The capacity of the INCD Lisbon center was also slightly improved with new compute servers aimed at HPC and GPGPU computing.

The LIP Tier-2 in the Worldwide LHC Computing Grid delivered more than 83 000 000 HEP Spec06 hours amounting to approximately 110% of the pledged capacity. With the upgrade to Slurm the grid computing elements were also redeployed with newer middleware implementations. The support for IPv6 in internet facing services was also finalized. Longer term requirements to address the increase of LHC luminosity are being pursued near the funding authorities.

Collaboration with FCT in the framework of the national advanced computing network (RNCA) continued with the participation in the RNCA Sherpas group that aims to establish the foundations and rules of participation for this network. In this context, LIP collaborated in the definition and evaluation of the first call for advanced computing projects (CPCA). This first call will provide computing time in operational centers of the RNCA network over a period of six months. INCD is one of such centers and will deliver cloud and HPC capacity to support 42 computing projects starting in January 2021. INCD will also support projects from the FCT call AI 4 COVID-19.

In the context of the EuroHPC initiative which aims to develop a world class supercomputing ecosystem in Europe, LIP participated in the preparation of the EuroCC project to deploy a long term network of national advanced computing competence centers in Europe. The project started in September 2020 and LIP participates in the national competence center in the areas of training, support and consulting for research and industry. LIP also coordinates the national activities related to communication, dissemination and outreach. Also related to HPC, the project BigHPC started in March a collaboration with industry, TACC (Texas Advanced Computing Center), and INESC-TEC to develop a management framework for consolidated Big Data and High-Performance Computing.

In the IBERGRID and EGI context, LIP ensured the national liaison and coordinated the operations of the Iberian distributed computing infrastructure and its integration in the pan-European EGI

infrastructure. IBERGRID delivers federated cloud, high performance and high throughput computing to support international projects and initiatives of common interest to Portugal and Spain. LIP and INCD supported projects in the area of Particle Physics, Life Sciences, Structural Biology, Coastal Engineering, Oceanography and Biodiversity among others.

LIP continued an active participation in the EOSC-Synergy project that aims at the alignment of national infrastructures and policies in Spain, Portugal, UK, Czech Republic, Germany, Slovakia, Poland and the Netherlands towards the implementation of the European Open Science Cloud (EOSC). The project was conceived in the IBERGRID framework. LIP is coordinating the work package on fostering service adoption where new tools are being developed following a quality based approach applied to software and services. In this context LIP coordinates the definition of the Quality Assurance baselines for software and services, and development of the Jenkins pipeline library v2 (JePL) that provides a straightforward way for software projects to be compliant with common Software Quality Assurance practices. LIP collaborated with LNEC in the integration of a new thematic service in the area of coastal engineering (WorSiCa) that leverages Copernicus images among other data sources. LIP and INCD, also participated in EOSC-Synergy in the area of capacity integration aiming at integrating and aligning new services in terms of policies and standards. Finally LIP is cooperating with FCT, which is also a partner in the project, to experiment with data repositories. Two approaches are being explored, using EUDAT data services for HPC applications and DataVerse for generic data repositories.

Also in the EOSC context the DEEP-Hybrid-DataCloud finished successfully with the development of a platform for deep learning and machine learning supporting artificial intelligence and processing of very large data. The EOSC-hub project is establishing technical foundations for EOSC and continued with LIP coordinating the Software Configuration, Change, Release and Deployment management activities for all cloud, grid and data oriented services. Furthermore, LIP also participated in the integration and support of OPENCoastS a simulation service for the European Atlantic coast developed in partnership with LNEC.

Finally proposals for new European projects were prepared namely EGI-ACE, EOSC-Future and C-Scale, these projects were approved and are starting in 2021.

Lines of work and objectives for next year

IT services

Continue the improvement and consolidation of the LIP core IT services. The objectives include the renewal of the storage spaces, virtualization systems, web services and core network. These objectives will be adjusted according to the funding level and schedule of the Associate Laboratory programme under which a budget for the next 5 years has been requested. The improvement of the IT processes and their automation though the new IT portal will continue.

WLCG and Tier-2

Operation and development of the Portuguese Tier-2. A small upgrade of capacity is expected using the remaining funding of INCD. A plan for larger upgrades to support the data and compute requirements associated to the LHC higher luminosity over the coming years is a priority. This will require the concerted engagement of all concerned parties. Alternative computing models and complementary solutions will be also followed and considered.

INCD

Coordination of the INCD technical and operational activities. For 2021 these activities include the renewal of the tape storage systems, small reinforcement of the computing farms and enlargement of the cloud computing service. The schedule of these activities will depend both on a request for extension to accommodate COVID-19 induced delays, and on the availability of housing space in the north of the country, currently under construction. Planning for a second phase of funding will be performed expecting the opening of a call to support the continuation of the national infrastructures roadmap. The team will support a growing number of users and projects from different domains. Under the Calls for Advanced Computing Projects and Artificial Intelligence, the INCD team will be supporting 42 new computing projects starting in January 2021. The compute projects under this first call will last 6 months after which new calls are expected to take place periodically.

EGI, IBERGRID and EOSC

Continue liaising Portugal with the European Grid Infrastructure (EGI) both at the governance and operational levels enabling the integration and exploitation of cloud, grid and data resources federated in this international infrastructure. The IBERGRID collaboration will continue providing an umbrella for Iberian participation in EGI. LIP will be the local organizer of next edition of the IBERGRID conference which has been delayed due to the COVID-19, and that hopefully will take place later in the year.

Finalize the participation in the EOSC-hub project where LIP coordinates the Software Configuration, Change, Release and Deployment management activities for all cloud, grid and data oriented services. LIP will support the udocker tool as part of the common services. Jointly with LNEC, will continue operating the OPENCoastS thematic service in EOSC providing on-demand forecasts for the European Atlantic coast. These activities will continue in the framework of both the EGI-ACE (starting in January) and EOSC-Future (starting in May). The EGI-ACE project will also extend the ongoing collaboration with the Portuguese and Spanish nodes of the Global Biodiversity Information Facility (GBIF) to the creation of a common information portal for Iberian biodiversity.

The EOSC-synergy project started in September 2019 and will continue aiming at the convergence of national infrastructures within

EOSC and promotion of the development and adoption of the EOSC services by scientific users. LIP coordinates the development of a platform for automated on-demand Software Quality Assurance and participates in the integration of thematic services in the European Open Science Cloud. Focus will be put on the piloting of scientific data repositories.

EuroHPC

Continue the participation in the EuroCC project. Establish the national structure for dissemination and communication in close articulating with EuroHPC and the European network of national competence centers. LIP is coordinating the communication and dissemination activities, and will provide support, training and consulting on advanced computing for research and innovation in the private and public sectors.

Other R&D&I projects

Continue participating in the BigHPC project in partnership with TACC, INESC-TEC and WAVECOM aiming at the development of an innovative management framework for Big Data and parallel computing workloads. Start in partnership with INCD the project C-Scale that aims to deploy a platform for earth observation data exploiting capacity and services from the EGI infrastructure.

Medium-term (3-5 years) prospects

The group activities will be largely driven by the participation in INCD, whose technical development and implementation is being coordinated by LIP. INCD is being mainly funded through the FCT infrastructures roadmap. The final investments in hardware are foreseen to take place during 2021 in Lisbon and 2022 in Minho. The medium term objective is to reinforce the INCD position so that it can apply for further funding from the national research infrastructures roadmap when possible. These activities are also tightly related to the participation in the Worldwide LHC Computing Grid whose Tier-2 capacity is being delivered using both hardware resources from INCD and human resources from LIP. With the ramp up of LHC luminosity the continuity and enlargement of the INCD infrastructure is of strategic importance.

Participation in international digital infrastructures is expected to continue. These include WLCG, EGI and IBERGRID. The activities will include improvement of the infrastructures via R&D projects, operations, delivery of services to international research communities and collaboration with research communities from other domains.

The group is enlarging its participation in High Performance Computing (HPC) related activities. HPC has been identified as a key development area both at national and European level whose importance is highlighted in Horizon Europe investment programme 2021-2027. Two approaches are being pursued: Participation in the national competence center in EuroHPC through the EuroCC project started in September of 2020; Provisioning of services to the research community through INCD in the context of the FCT advanced computing network (RNCA), including support to the FCT calls for advanced computing projects and artificial intelligence among others.

The participation in the European Open Science Cloud will continue with the participation in new EOSC related projects such as EGI-ACE, C-Scale and EOSC-Future. These activities are being extended to the national level through the cooperation with FCT-FCCN in the domain of scientific data repositories.

The group will continue exploiting synergies with other organizations, especially in the context of INCD, aiming at collaboration in the implementation of platforms and solutions adapted to the needs of these user communities. Examples are GBIF, LifeWatch/PORBIOTA, Elixir/BIODATA and CoastNET. Finally participation in further R&D&I projects will be pursued in the context of ongoing collaborations (IBERGRID, EGI, INDIGO-DC) exploiting opportunities in the context of Horizon Europe and Digital Europe.

SWOT Analysis

Strengths

- Extensive knowledge and experience in scientific computing.
- Participation in international scientific e-infrastructures and initiatives.
- Operating the Portuguese WLCG Tier-2 under the CERN LHC computing MoU.
- Partnership with FCCN and LNEC and other organizations via INCD.
- Participation in the FCT infrastructures roadmap.
- Users from multiple disciplines and organizations.

Weaknesses

- Lack of compute and storage capacity.
- Cash flow and administrative limitations.

Opportunities

- Maintain and improve the IT infrastructure services in partnership with INCD.
- Enable policies for scientific computing and open access.
- Potential for industrial and e-government applications.
- Possibility of engagement with other communities.
- Expand activities to high performance computing and data repositories.

Threats

- Lack of resources to fulfill the WLCG and other large requirements.
- Lack of funding for operational costs.
- Exacerbated focus towards supercomputing.

GRID

Publications

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

- *"A cloud-based framework for machine learning workloads and applications"*, Álvaro López García; Jesus Marco, Marica Antonacci, Wolfgang zu Castell, Mario David, Marcus Hardt; Lara Lloret Iglesias; Viet Tran; Germán Moltó, Marcin Plociennik, Andy S Alic, Miguel Caballer, Isabel Campos Plasencia, Alessandro Costantini, Stefan Dlugolinsky, Doina Cristina Duma, Giacinto Donvito, Jorge Gomes, Ignacio Heredia, Keiichi Ito, Valentin Kozlov, Giang SCC Nguyen, Pablo Orviz Fernandez, Zdenek Sustr, Pawel Wolniewicz, Á. L. García et al.,
- *"OPENCoastS: An open-access service for the automatic generation of coastal forecast systems"*, A. Oliveira, A.B. Fortunato, J. Rogeiro, J. Teixeira, A. Azevedo, L. Lavaud, X. Bertin, J. Gomes, M. David, J. Pina, M. Rodrigues, P. Lopes, S.Bernardo, Environmental Modelling & Software, 2019, 104585, ISSN 1364-8152
- *"Software Quality Assurance in INDIGO-DataCloud Project: a Converging Evolution of Software Engineering Practices to Support European Research e-Infrastructures"*, Pablo Orviz, Mário David, Jorge Gomes, Doina Cristina Duma, Elisabetta Ronchieri, Davide Salomoni, J. Grid Comput. 18 (2020) 81-98

3 International Conference Proceedings

- *"OPENCoastS: a tailored coastal forecasting WebGIS service"*, Anabela Oliveira, Alberto Azevedo, André B. Fortunato, Marta Rodrigues, João Rogeiro, Pedro Lopes, Samuel Bernardo, Jorge Gomes, João Pina, Mario David, 3rd Conference of the Arabian Journal of Geosciences (CAJG), 2-5 November 2020, Sousse, Tunisia
- *"Report on the Workshop on Sustainable Software Sustainability 2019 (WOSSS19)"*, Shoaib Sufi et.al,
- *"RESCCUE RAF App - Using Technology to Mitigate Climate Change Urban Impacts"*, P.Lopes, A.Oliveira, C.Pereira, R.S.Brito, M.A.Cardoso, R.Martins, M.David, J.Gomes, J.Pina, P.Lopes, A.Oliveira, C.Pereira, R.S.Brito, M.A.Cardoso, R.Martins, M.David, J.Gomes, J.Pina, RESCCUE RAF App - Using Technology to Mitigate Climate Change Urban Impacts, Mipro2020, ISSN 1847-3946, pp 1959-1963

12 Collaboration notes with internal referee

- *"EOSC-hub D10.4 EOSC Hub Technical Architecture and standards roadmap v2"*, J.Pina (LIP), D.Scardaci, G. Donvito, M. Sanden, L. Dutka, G. Fiameni, H. Widmann, I. Blanquer, E. Fernandez, M. Antonacci, M. Plociennik, J. Jensen, M. Prochazka, L. Florio, O. Appleton, EOSC-hub project deliverable
- *"EOSC-Synergy EU Milestone 3.1: Software Quality Pipelines Implemented in the Services"*, P.Orviz, J.Gomes, EOSC-synergy project milestone
- *"EOSC-Synergy Deliverable D4.1: Best Practices Elicitation including Data Management Plans"*, I.Blanquer, J.Gomes, M.David, EOSC-synergy project deliverable
- *"State of the art regarding digital badge issuing technologies"*, G.Molto, M.Caballer, P.Orviz, M.David, J.Gomes, EOSC-Synergy white paper
- *"EOSC-Synergy EU Milestone 3.2: Quality baseline defined"*, M.David, J.Gomes, P.Orviz, J.Pina, S.Bernardo, EOSC-synergy project milestone
- *"EOSC-synergy: A Set of Common Service Quality Assurance Baseline Criteria for Research Projects"*, M.David, P.Orviz, J.Gomes, S.Bernardo, I.Campos, G.Moltó, M.Caballer, ,
- *"EOSC-Synergy EU Deliverable: D3.1 Software Maturity baseline"*, M.David, J.Gomes, G.Molto, M.Caballer, P.Orviz, S.Bernardo, J.Pina, V.Tykhonov, EOSC-synergy project deliverable
- *"EOSC-Synergy EU Deliverable: D3.3 Intermediate report on technical framework for FAIR principles implementation"*, W.Steinhoff, G.Coen, I.Bernal, A.Azevedo, S.Bernardo, F.Aguilar, Tykhnov, EOSC-synergy project deliverable
- *"EOSC-Synergy EU Milestone 3.2: Working CI/CD pipeline for WorSiCa thematic service"*, S.Bernardo, P.Orviz, J.Gomes, M.David, EOSC-synergy project milestone
- *"EOSC-Synergy EU Deliverable: D3.2 First prototype of the Service Integration platform"*, P.Orviz, J.Gomes, G.Molto, D.Naranjo, M.David, S.Bernardo, EOSC-synergy project deliverable
- *"EOSC-Synergy EU Deliverable D2.2: Intermediate report on integration efforts"*, M.Hardt, I.Campos, A.Garcia, J.Gomes, EOSC-synergy project deliverable
- *"EOSC-Synergy Deliverable D2.1: Roadmap for Integration of National Capacities into the EOSC and Policy Gap Analysis"*, M.Hardt, I.Campos, A.Garcia, J.Gomes, EOSC-synergy project deliverable

Presentations

6 Oral presentations in international conferences

- Jorge Gomes: *"Scientific computing with Linux containers"*, 2020-06-16, EXALAT - Lattice Field Theory at the Exascale Workshop
- Samuel Bernardo: *"EOSC-Synergy Jenkins Pipeline Library Demonstration"*, 2020-11-01, EGI Conference 2020,
- Isabel Campos: *"Roadmap towards expanding capacity, services and user base"*, 2020-11-02, EGI Conference 2020,
- João Rogeiro: *"Generating on-demand coastal forecasts using EOSC resources: the OPENCoastS service"*, 2020-11-02, EGI Conference 2020,
- Samuel Bernardo: *"Integration of WORSICA's thematic service in EOSC - challenges and achievements"*, 2020-11-02, EGI Conference 2020
- Mário David: *"A quality based approach to software and services"*, 2020-11-03, EGI Conference 2020

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

- João Pina: *"DEEP framework for deep learning"*, 2020-06-23, ISC High Performance 2020, Frankfurt

5 Oral presentations in national or international meetings

- João Pina: *"LIP Computing Services and Infrastructures "*, 2020-02-14, LIP Workshop 2020, University of Minho, Braga
- Mário David: *"LIP Computing Projects"*, 2020-02-14, LIP Workshop 2020, University of Minho, Braga
- Jorge Gomes: *"LIP Computing Activities Status and Perspectives"*, 2020-02-14, LIP Workshop 2020, University of Minho, Braga
- Mário David: *"The Current Onboarding Procedures, Rules of Participation EOSC-Synergy"*, 2020-02-27, EOSC Architecture Work Group Service Onboarding Task Force,
- Mário David: *"EOSC-Synergy"*, 2020-03-26, Joint meeting between EOSC-Synergy and CESSDA

GRID

3 Presentations in national conferences

- João Pina: *"Computing at LIP"*, 2020-03-28, Symposium on Data Science: Bringing Fundamental Research and Industry, University of Minho, Portugal
- Jorge Gomes: *"INCD - Infraestrutura Nacional de Computação Distribuída"*, 2020-10-14, FCCN eJornadas 2020,
- Jorge Gomes: *"Infraestrutura Nacional de Computação Distribuída"*, 2020-11-04, Encontro Ciência 2020, Centro de Congressos de Lisboa

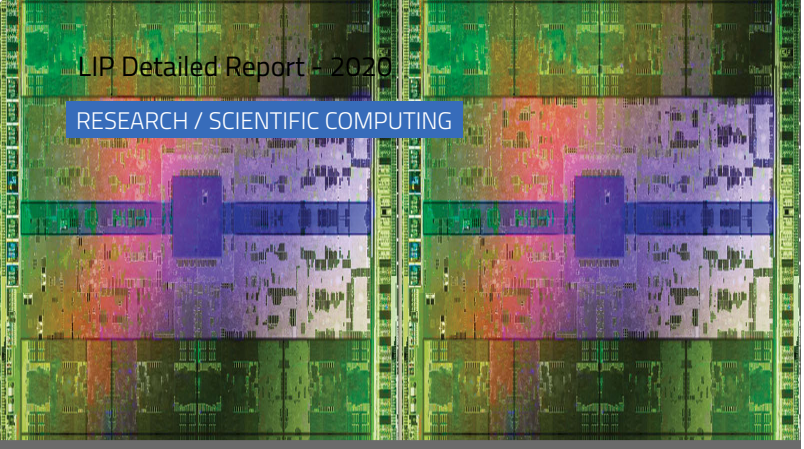
1 Seminar(s)

- Mário David: *"Software Development in modern days: DevOps methodology"*, 2020-12-02, ISCTE-IUL seminar, ISCTE, Lisbon

Organized Events

1 Collaboration Meeting(s)

- *"EOSC-Synergy 3rd All Hands Meeting"*, [Coll-Mtg] 2020-09-22 / 2020-09-25, Virtual Zoom



ADVANCED COMPUTING

Advanced Computing

Principal Investigator:
António Pina (75)

2 ***Master Student(s):***
Tiago Duarte (100), Tiago Gonçalves (100)

3 ***External collaborator(s):***
António Esteves, José Rufino, Vítor Oliveira

Total FTE:
2.8

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 encompasses R&D on the combination of traditional multicore CPUs with acceleration devices. The group, part of 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 main areas of interests of LIP research. In particular, it is noteworthy the support to the development and optimization of code applications related to high energy physics (HEP) 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 for 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 in LIP and a CPU/GPU system dedicated to machine learning simulation.

Advanced Computing

Overview

It is a small group whose work is mainly focused in the following directions:

- application performance analysis;
- dynamic tracing;
- parallelization strategies for GPU-based algorithms;
- HPC: support to computer cluster infrastructures;
- machine learning and training;
- advanced training: Linux, Concurrent C++.

Assessment of the past year: objectives vs. achievements

The work developed closely followed the objectives set for the year 2020. In this context, the emphasis was placed on the following activities:

- To continue the process of enriching the pedagogical projects for which we are responsible, to include the research / development on areas more directly related to high energy physics software in order to encourage the incorporation of young researchers in the work of LIP;
- Launching of new computer training activity for young researchers;
- Involvement in the ATLAS collaboration.

The activities developed by the group included:

- On the context of project “BigDataHEP: Understanding Big Data in High Energy Physics”:
  - ongoing Master thesis related to the “Distributed Training of Deep Neural Networks”,
  - ongoing Master thesis related to parallel/distributed multithread programming: "Study, evaluation and application of the HPX platform".
- 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 2021, 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 cluster infrastructure and the CPU/GPU machine learning system.

We also expect to be able to attract new students for R&D in the group main scientific areas, in particular:

1. i) performance analysis of HEP data analysis applications
   ii) evaluation of alternatives to developing hybrid shared/distributed memory applications
   iii) development of a platform intended to allow the efficient processing of data in the context of “Understanding Big Data in High Energy Physics”.

In the context of the group participation on the ATLAS upgrade 2019/20 and based in our previous work on ATLAS High-Level Trigger we plan:

- to submit a project following the FCT (2020/2021) Call for SR&TD Project Grants in all scientific domains.

On the continuation of the the process of enriching the pedagogical projects for which we are responsible, to include the research / development on areas more directly related to HEP software in order to encourage the incorporation of young researchers. In accordance with this objective, we foresee the completion of two new Master theses. 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 combine traditional multicore CPUs with acceleration, with the algorithm “ATLAS Topological Clustering using GPUs and CUDA" as a case study.

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 eventual success in the applications for FCT Call for SR&TD Project Grants and the doctoral thesis CERN PhD Grants Program could represent a turning point in the research activities of our group.

SWOT Analysis

Strengths

- A group with solid foundation in parallel and distributed computing scientific domains;
- International R&D collaboration experience as a result of the active participation in several EU FP6/FP7 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

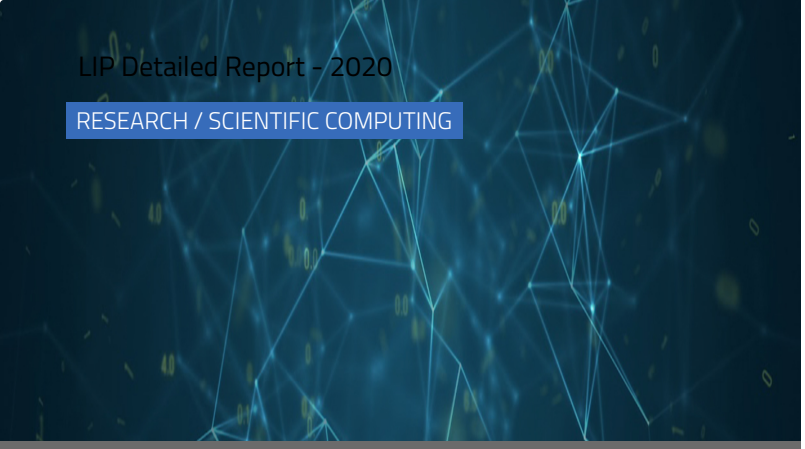
- We are currently a small group, clearly insufficient to take advantage from the scientific and industrial potential of one of the youngest regions in Europe.

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 due to 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 Master or PhD.



SPAC (*)

Social Physics and Complexity

Principal Investigator:
Joana Gonçalves-Sá (85)

4 ***Researcher(s):***
Alexander Davidson (100), Cristina Mendonça (100), Lília Perfeito (100), Simone Lackner (100)

2 ***Technician(s):***
Paulo Almeida (100), Rita Saraiva (50)

1 ***PhD Student(s):***
Sara Mesquita (100)

3 ***Master Student(s):***
David Almeida (100), José Reis (100), Pedro Araújo (100)

2 ***External collaborator(s):***
Afonso Manuel Marques, Sofia Pinto

Total FTE:
10.3

Articles in international journals:	**1** Direct contribution
Proposals:	**2**
International conferences:	**5** Oral presentations
	1 Poster
Advanced Trainin Events:	**3** Oral presentations
Seminars:	**3** Seminars
	6 Outreach seminars

(*) Percentages are for 2021, as most of the group started in late 2020

Executive summary

The Social Physics and Complexity (SPAC) Lab joined LIP during the second half of 2020. SPAC 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 very multidisciplinary with members having backgrounds in Physics, Mathematics and Computer Sciences, but also in Biology, Neurosciences, Psychology, and Law. Together, the group takes advantage of the so-called "Big-Data Revolution" 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 biases, and works to establish guidelines for ethical uses of data science and artificial intelligence.

In 2020, other than the logistic challenges of moving and starting a new group during a lockdown, SPAC's efforts have been focused on studying two parallel pandemics: one caused by a virus on real contact-networks and the other driven by misinformation, mostly on online social media.

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)".

Sources of funding

PI	Code	Amount	Dates	Description
Joana Gonçalves-Sá	FARE - Fake News and Real People (ERC)	1.499.844 €	2020-10-01 / 2025-09-30	Grant Agreement 853566

Total: 1.499.844 €

SPAC

Overview

Understanding complexity has always been a hallmark of physics research and, 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 is offering radically new ways to study complex social behaviours and this is being recognized by physics and computer science departments in many top universities worldwide. The combination of large-scale data sources and a growing toolbox from machine learning and big data analytics is making it easier to extract patterns and offer some predictions.

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.

During 2020 the group moved to LIP and started an ERC Starting grant. It currently has 11 members and is strongly involved in the COVID-19 pandemic mitigation efforts.

Assessment of the past year: objectives vs. achievements

2020 was a particular year in many aspects, requiring strong adaptation skills. SPAC's PI started at LIP in July 2020 and the rest of the team from October onwards. Equipment was moved in late December. Many of the challenges have been logistic and of sustaining research while moving and developing infrastructure. In particular three main goals were accomplished:

1. Building team capacity, maintaining team spirit and mental health;
2. Supporting the pandemic control efforts;
3. Sustaining ongoing research.

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.

This allowed setting up the necessary management organization and increasing team capacity.

SPAC has significantly expanded to 11 members, and is now composed of: 1 PI, 4 Post-doctoral researchers (supported by FARE or by 2 FCT-funded projects), 1 PhD student (individual FCT fellowship), 3 Master students, 1 Data Manager and 1 Project Manager (half-time). 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 lab members. Given the current pandemic context, the remote work, and the fact that most SPAC members are new to the lab, particular care was taken to ensure lab members became familiar with each other and their very distinct skill sets.

Research outputs and Science Communication

The group finished one FCT-funded project, on reducing antibiotic overprescription, still managed by the PI's previous institution (Nova SBE). This project was a pilot of current efforts to improve public administration through data science and artificial intelligence, and will give rise to one research paper and one policy report.

The group finished a long-term project on analysing 40 years of Portuguese political discourse. This work has led to a large corpus of the parliamentary debates (accepted for publication in September 2020), one searchable repository, open for free access to journalists and the scientific community, and one in-depth report, sponsored by the Calouste Gulbenkian Foundation, on the public salience of "Intergenerational Justice", as a political concept (online December 2020). Two other manuscripts are in preparation, one to be published during 2021.

Research on the current pandemic has led to two working papers, both already on MedRxiv. One is a collaboration with colleagues from the Physics department at IST and the other corresponds to the first scientific output of the group's PhD student. Both papers have already been submitted for publication. In parallel, several group members are actively collaborating with national health authorities on mitigation and information capacity building.

Several group members had their work accepted into the main conferences in the field. Together, SPAC members orally presented 3 abstracts, 2 posters/lightning talks, and gave 1 keynote lecture since joining LIP.

SPAC's PI is strongly involved in science communication and outreach and finished in December 2020 a long-term collaboration with Instituto Gulbenkian de Ciência, to improve critical thinking, science education and citizen science. The group has also published opinion articles and commentary on pandemic control.

Overall, SPAC has accomplished several important goals and is in a very good position to begin 2021.

Lines of work and objectives for next year

In 2021, SPAC expects to continue establishing itself as a leading research group in complexity and social physics and increasing its national and international standing.

Current research projects include:

1. 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 2020, with strong emphasis on research and supporting the mitigation efforts of the COVID-19 pandemic and will continue in 2021. 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.
2. Political Discourse and Public Politics, particularly by using a combination of tools including text mining, media analytics and natural language processing to analyse large periods of the Portuguese democracy and uncover patterns and dynamics. This project will be significantly reduced in 2021, with the publication of the current working papers and the graduation of a Master student (in collaboration with Nova SBE) who studies corruption salience in public and political contexts.
3. 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 2021 (details below).

Human Resources:

Following the strong growth of 2020, 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 the ERC project 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 and Outreach:

Most effort will be dedicated to:

1. Continue 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. Creating a pipeline for social media analysis, including users and information networks (with a strong focus on the Twitter platform);
3. Creating a dataset of “fake news” and other sources of misinformation;
4. Designing 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 with the LIP community;
7. Improving science communication and outreach, particularly in the area of ethical risks of AI, including the development of a bi-lingual website;

Overall, SPAC expects to start 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.

Research lines 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 the concept of treating humans as particles, and interesting research will emerge from applying theoretical models from physics (ex. fluid dynamics, statistical physics) and simulations (ex. Monte Carlo) to the 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 5 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.

Finally, the group accepts its strong social responsibility and, in 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

Unconsolidated team working exclusively online; Limited history of collaboration with researchers at LIP or with LIP's main research partners;

Opportunities

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 journal(s)
(with direct contribution from the team)

- *" PTPARL-D: An Annotated Corpus of 40 years of Portuguese Parliamentary Debates."*, Paulo Almeida, Manuel Marques-Pita, Joana Gonçalves-Sá, Corpora

2 Proposal(s)

- *"A data-driven epidemiological model to explain the Covid-19 pandemic in multiple countries and help in choosing mitigation strategies"*, M. J. Beira, A. Kumar, L. Perfeito, J. Gonçalves-Sá, J. Sebastião, medRXiv
- *"Intergenerational Justice and Sustainability – An Analysis of Parliamentary Speeches and Media "*, Lília Perfeito, Paulo Almeida and Joana Gonçalves-Sá , Calouste Gulbenkian Foundation

1 Article in Outreach Journal

- *"Temos poucas ferramentas para travar a pandemia"*, Joana Gonçalves-Sá , Visão

Presentations

5 Oral presentations in international conferences

- Joana Gonçalves-Sá: *"Thoughts on why people share fake news - using data to understand behaviour (Keynote speaker)"*, 2020-09-18, NetSci2020 satellite Workshop: Political Communication Networks, online/Rome (Italy)
- Lília Perfeito: *"A popularity model for information spreading: Twitter as a case study"*, 2020-12-03, Complex Networks 2020, online/Madrid (Spain)
- Joana Gonçalves-Sá: *"Using pandemics to improve now-casting models"*, 2020-12-08, Complex Systems Society 2020, online
- Simone Lackner: *"A little knowledge is a dangerous thing: excess confidence explains negative attitudes towards science."*, 2020-12-09, CSS20 satellite Workshop: Citizen Social Science & Complex Systems Science, online
- Joana Gonçalves-Sá: *"A little Knowledge is a Dangerous Thing: Excess Confidence Explains Negative Attitudes Towards Science"*, 2020-12-11, Complex Systems Society 2020, online

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

- Sara Mesquita: *"Using pandemic periods to improve now-casting models based on search engine data"*, 2020-12-02, Complex Networks 2020 , online/Madrid (Spain)

3 Oral presentations in advanced training events

- Joana Gonçalves-Sá: *"Revolução Digital e desafios à liderança"*, 2020-07-17, Leadership Executive Education - Nova SBE, online
- Cristina Mendonça: *"Introdução a experiências e estudos online: Preocupações, planeamento e plataformas"*, 2020-11-16, Escola de Outono: Métodos de Investigação e Migrações - Faculdade de Psicologia da Universidade de Lisboa, online
- Cristina Mendonça: *"Introduction to HTML, CSS, and JavaScript for Qualtrics"*, 2020-11-16, ICS - Universidade de Lisboa, online

3 Seminars

- Joana Gonçalves-Sá: *"Walking the talk: a computational approach to differences between votes and political discourse"*, 2020-07-02, SPARC GI Seminars, ICS - Universidade de Lisboa, online
- Joana Gonçalves-Sá: *"Focusing the macroscope: how we can use data to understand behaviour"*, 2020-09-17, LIP Seminar, online/Lisbon (Portugal)
- Joana Gonçalves-Sá: *"What is Social Physics?"*, 2020-11-18, Colóquios do Departamento de Física IST, online/Lisbon (Portugal)

6 Outreach seminars

- Joana Gonçalves-Sá: *"COVID19 + MedTech (panel discussion) "*, 2020-09-24, Covid-19, MedTech e o Futuro da Saúde, Lisbon, Portugal
- Joana Gonçalves-Sá: *"O potencial da indústria dos dados, porque partilhamos notícias falsas e o dilema entre o potencial e o poder dos algoritmos: uma conversa entre Diogo Queiroz de Andrade e Joana Gonçalves de Sá"*, 2020-10-08, A Europa aos 70 (podcast),
- Joana Gonçalves-Sá: *"Desafios regulamentares e societais: o que nos espera? (panel discussion)"*, 2020-10-10, 4º Encontro de Cientistas Portugueses em França, online
- Joana Gonçalves-Sá: *"Os Desafios da Inteligência Artificial na Máquina do Estado (panel discussion)"*, 2020-11-03, Ciência '20, Lisbon, Portugal
- Joana Gonçalves-Sá: *"Digital Pandemics"*, 2020-11-13, XV Medical Students' Cooperation Meeting, online
- Joana Gonçalves-Sá: *"Pessoas informadas, pessoas ciberseguras (panel discussion)"*, 2020-11-23, C-DAYS 2020, Cascais, Portugal

Theses

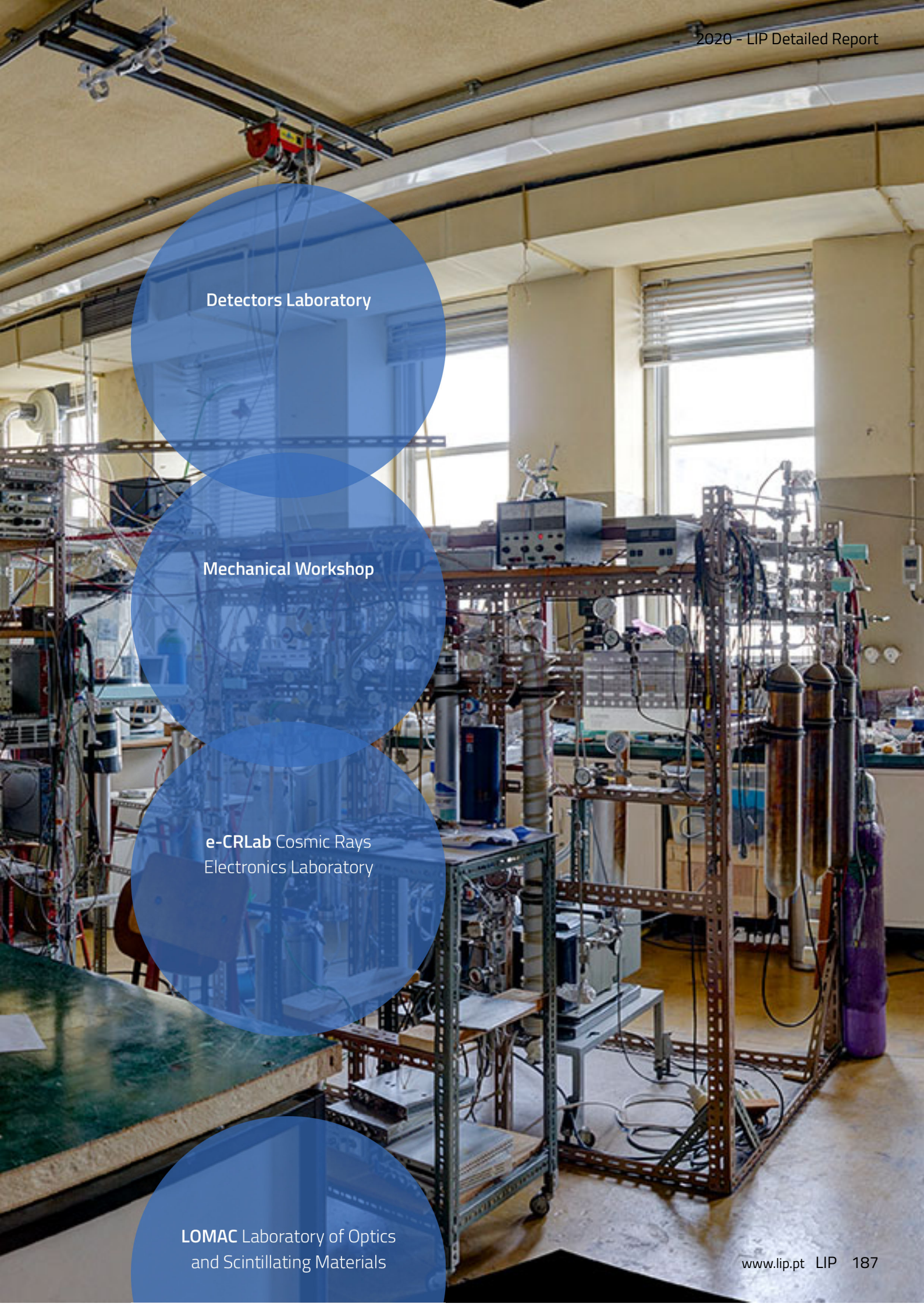
1 PhD

- Sara Mesquita: *"Using online behaviour to track global outbreaks and pandemics"*, 2020-09-01, (ongoing)

1 Master

- David Almeida: *"Follow the (scientific) leader: the impact of crisis on trust in scientific authorities"*, 2021-09-30, (ongoing)

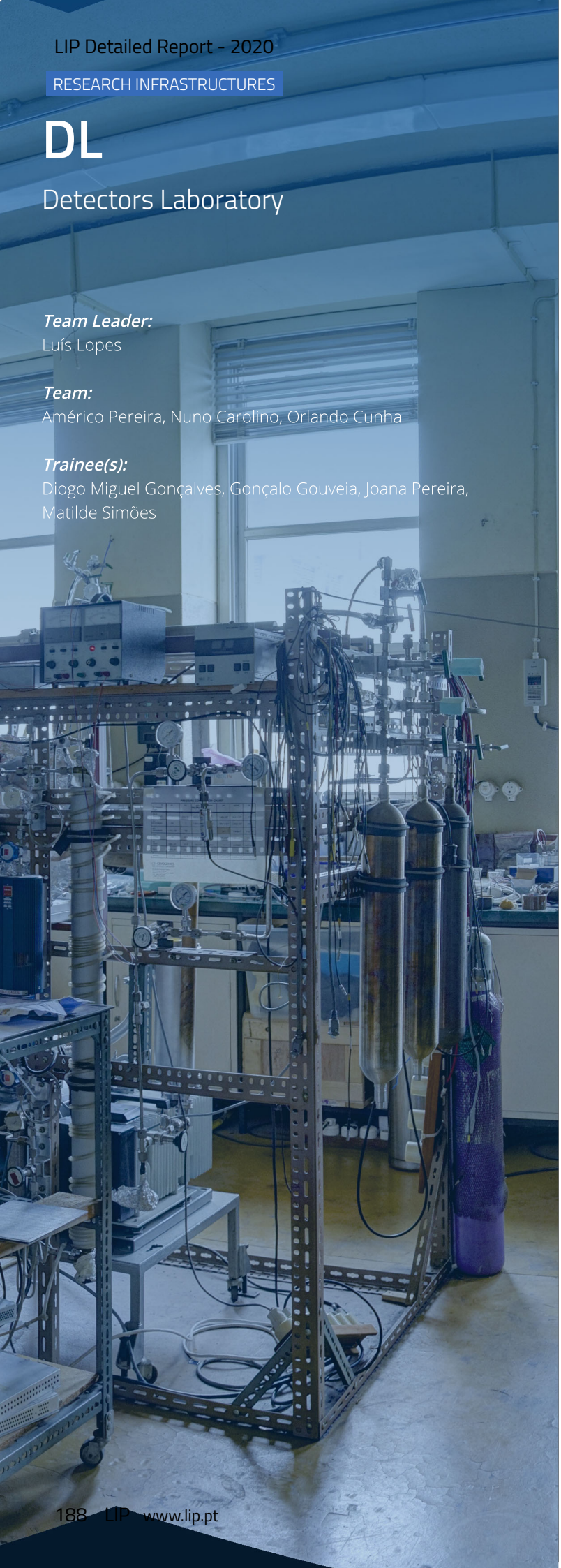
RESEARCH Facilities


Detectors Laboratory
Mechanical Workshop
e-CRLab Cosmic Rays Electronics Laboratory
LOMAC Laboratory of Optics and Scintillating Materials

RESEARCH INFRASTRUCTURES

DL

Detectors Laboratory



Team Leader:
Luís Lopes

Team:
Américo Pereira, Nuno Carolino, Orlando Cunha

Trainee(s):
Diogo Miguel Gonçalves, Gonçalo Gouveia, Joana Pereira, Matilde Simões

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 most of its commitments, and was partner in initiatives to help fighting COVID-19 in which LIP members participated.

The main activities in 2020 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, but there was a reduction with respect to previous years due to the COVID-19 pandemic. R&D and production of new products for outreach is another goal postponed to next year due to the pandemic. As a highlight of 2020, the first real size prototypes of a sealed RPC were built and tested.

Detector Lab

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 at University of Coimbra, it is equipped with 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 sensitive parts of the detectors, a room for painting and large area for detector integration and test.

Assessment of the past year: objectives vs. achievements

While most of LIP was in telework mode from mid-March until de end of 2020, the DL and other scientific infrastructures were the main exception, as they went back to work as soon as they could comply with the new sanitary regulations. While the pandemic impacted the activity plan in several ways, they managed to keep most of their commitments, and they were partners in initiatives to help fighting COVID-19 in which LIP members participated.

As a highlight of 2020, the first real size prototypes of a sealed RPC were built and tested. The results were very well accepted by the RPC community. New chambers were built to test different gap sizes and numbers.

The main activities in 2020 concerned the R&D and production of three different types of large area Resistive Plate Chambers (RPCs) used in experiments and projects in which LIP is involved, namely MuTom, 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 all the environmental properties that could affect it. Other parts and systems are developed in collaboration with the project researchers. This work consumed around 30% of our total human resources.

A fundamental role of the DL is the continuous support it provides to all groups performing R&D activities. In 2020 the DL contributed technical work and added value to the following projects: HiRezBrainPET, Dune, HADES-TOF and HADES-FD, SINE2020, Cloud Chambers, GSPC.LIP, OrthoCT, CCMC_ECOTOP, CSilva-IFCT, STRATOSPOLCA and COVID19. 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 centres has considerably increased.

Management and organization tasks included the maintenance and upgrade of both the DL and the Mechanical Workshop (MW); the creation of a database available to all collaborators with all existing materials, modules, instruments and tools; and the purchase of materials and instruments for LIP-Coimbra and the Physics Department of UC.

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 15 k€ (around 12% of the annual staff cost). The reduction with respect to previous years was largely due to the COVID-19 pandemic. Particularly relevant was the work done for the MAREFOZ Laboratory. A Spark Chamber was sold to the Science Center of Luxembourg. At the customer's request new features were added, which increased the quality of the product. All the material to build five more chambers was acquired and is in stock.

Lines of Work and objectives for next year

The plan for 2021 can be outlined as follows:

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 directly from last year, since it could not be fulfilled due to the pandemic.

In 2021, the DL will achieve the construction of the first large area muon telescope with sealed RPCs. 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. We will complete the modules for HADES-FD, STRATOS and HiRezBrainPET. Also scheduled is the production of four Spark Chambers.

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 become available.

Concerning the support to other groups, the DL is expected to contribute to the constructing, assembly and test of the following projects and/or setups: RPCs for neutrons within SINE2020; Cloud Chamber; GSPC.LIP; HADES; Dune; CCMC_ECOTOP; CSilva-IFCT. There will be, in addition, R&D contributions for several projects, namely HADES-MDC and muTom RPCs. 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 to 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 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 maybe we need to readjust the objectives in the next year. Nevertheless we already had some contacts and good indications for the delivery of three spark chambers.

We hope to continue to upgrade our capability 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 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 abilities.

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.
- Approximately 20 to 25% of 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 programming.
- There is frequently inefficiency (waste of time) due to bad preparation of the work when our collaborators/clients do not consult the DL experts beforehand. We systematic alert our collaborators for the need to do so, but the problem seems to be getting worse when compared with past years.

Opportunities

- The confirmed ruggedness and performance of some of our detectors has been opening novel markets. After projects such as muTT and Antarctica we were now in STRATOS. 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 spark chamber and the cloud chamber, may also play an important role in spreading our name/brand. New instruments should be considered.
- In the collaborations we belong to, some updates and construction of new detectors are opportunities that we must consider, in a 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 implementation of the products already developed.

Threats

The uncertainty in some of our funding sources in medium and long term.

RESEARCH INFRASTRUCTURES

MW

Mechanical Workshop

Team Leader:
Alberto Blanco
(Luís Lopes, starting from 2021)

Team:
Carlos Silva, Douglas Lima (*), Jorge Moreira, Nuno Filipe Silva Dias, Rui Alves

(*) Left in August 2020

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 the staff (two technicians and three engineers) allow the MW to perform a large spectrum of mechanical services, from the project to the 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 it 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 the 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 levels.

Workshop

Overview

The Mechanical Workshop (MW) is well prepared in terms of both equipment and specialized human resources. There are a number of modern CNC (Computer Numerical Control) machines that allow complex jobs to be performed. The ability to monitor any work from the beginning, including the mechanical project design, allows a faster response to all needs. In this way, the production can start to be prepared at an early stage, contributing for an optimized execution of each job.

Assessment of the past year: objectives vs. achievements

The objectives for 2020 as stated in the last report were:

- Design and construction of the complete mechanics for **HrezBrainPET.**
- Design and construction of mechanics for a **laser calibration system** for the **protoDUNE TPC.**
- Construction of the complete mechanics of **HADES RPC-FD**, four sectors with 32 individually shielded RPCs each.
- Construction of cloud chambers and spark chamber for outreach.

Despite the COVID-19 pandemic that forced us to close for about a month, 2020 has been a year with 55 open worksheet (to be compared with 54 in 2019, 60 in 2018) and 100% of the time occupied. Here is a list of the main (larger) projects:

- Design of the complete mechanics for **HrezBrainPET** and construction of the head #0.
- Design of parts of the mechanics for a **laser calibration system** for the **protoDUNE TPC**, in particular mirror holders, setup for testing mirrors and rotatory and isolation flange and corresponding construction of 6 units of mirror holders and test setups.
- Construction of the complete mechanics (including main frame and modification of different tools for construction) for two sectors of **HADES RPC-TOF-FD** and most of the parts for the remaining two + one (spare).
- Different elements (HV, HV filter, DAQ and control boxes) for **STRATOS** project (LIP).
- Gas accessories (UC, DL, LibPhysUC, LIP, GIAN).
- COVID-19 protection systems (UC).
- COVID-19 face shield and ear protection system (LIP, UC, Maternidade Bissaya Barreto Coimbra, Hospital Santamaria Lisboa and other small institutions).
- Several pieces for ventilator, **openAir initiative** (LIP).
- Sealed box for **MUTOM** DAQ (LIP).
- Low pressure box (Faculdade de Medicina Universidade de Coimbra, iCBR).
- Styrofoam collimator for microwave guide system (Instituto de Telecomunicações – Coimbra, Departamento Engenharia Electrotecnica e de Computadores).
- Stainless steel support (Associação Inovação e desenvolvimento da FCT).
- Macor pieces (LibPhysUC, Associação de Desenvolvimento do Departamento de Física ADDF).
- Radiotherapy support (Instituto Português Oncologia de Coimbra Francisco, Gentil E.P.E).
- DAQ box for **STRATOSPOLCA** project (LIP).
- Egg support **Monitoring and Control** (LIP).
- Multiple pieces for **LZ** group (LIP).
- Stainless steel support for Vacuum evaporation chamber (LIP).

Finally, our experienced lathe operator left LIP in mid-2020. The new MW element (J. Moreira) has fully taken up his position and demonstrated his ability autonomously.
The coordinator of the MW was changed to Luis Lopes at the end of 2020.

Lines of Work and objectives for next year

A few large projects are already allocated for 2021. Most of them are the continuation of previous projects that suffered delays/extensions (not necessarily due to the MW). The most significant ones are listed here:

- Construction of the complete mechanics for **HrezBrainPET.**
- Design and construction of mechanics for a laser calibration system for the **protoDUNE TPC**.
- Construction of mechanics for **HADES RPC-FD,** two + one sectors with 32 individually shielded RPCs each (most of the work is already done).
- Construction of cloud chambers.

Medium-term (3-5 years) prospects

Besides the continuous work for the LIP research projects and external groups/companies, in the next years we plan to consolidate/improve the MW:

- We need to consolidate the new lathe operator.
- We want to uniformize the software tools that we use both in project and production. The use of different tools leads to many small but complicated and annoying problems. In this line, we want to connect all the old CNC machines to our CAN software, which will improve performance. This is actually work in progress.
- Installation of the new machine with 3x3 m² working area and exploration of all its capabilities.

SWOT Analysis

Strengths & Opportunities

- Valuable know-how, experience and skills of the technical staff.
- Opportunity to extend our services to other research groups / companies.
- New capabilities with a new large-area CNC machine.

Weakness & Threats

- Difficulty in working simultaneously in many projects.
- Obsolescence of some of the equipment.

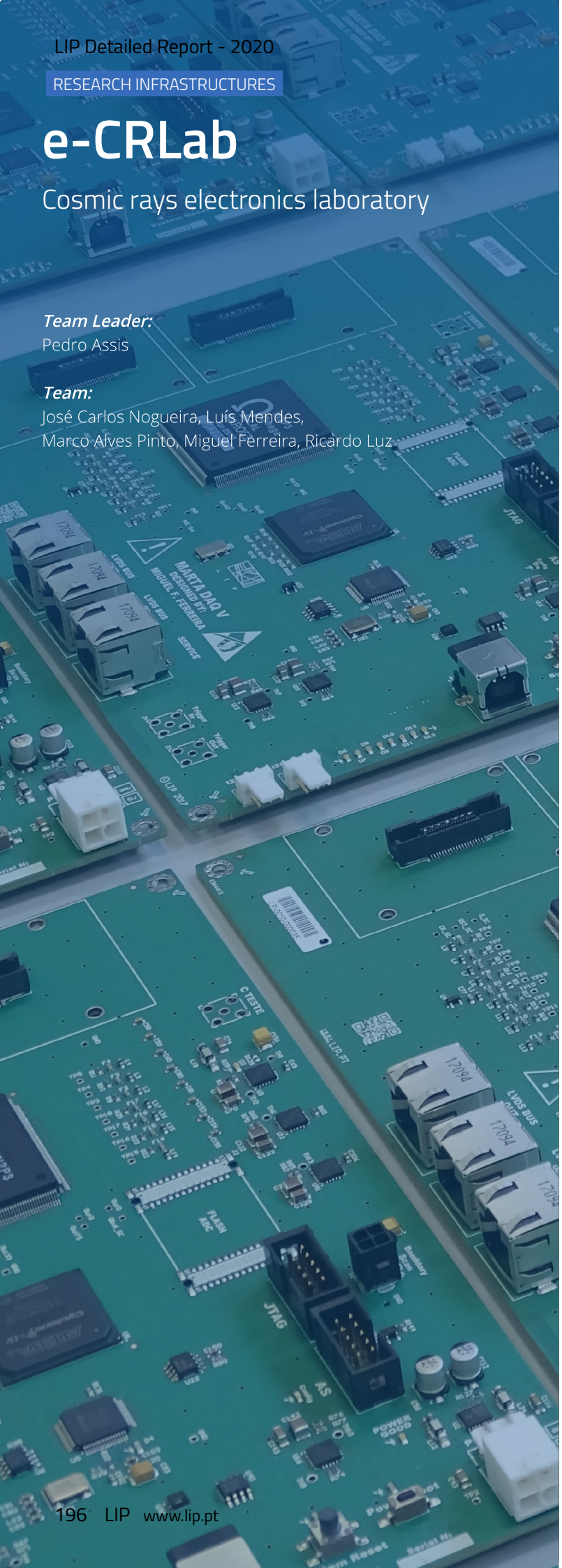
RESEARCH INFRASTRUCTURES

e-CRLab

Cosmic rays electronics laboratory

Team Leader:
Pedro Assis

Team:
José Carlos Nogueira, Luís Mendes,
Marco Alves Pinto, Miguel Ferreira, Ricardo Luz



Executive summary

The e-CRLab is mainly dedicated to the development of electronics for Cosmic Ray (CR) experiments. The focus is put on fast digital electronics implemented in FPGAs. The laboratory has the capability to design complex printed circuit boards (PCB) and to produce simple printed circuit board prototypes. The production of complex PCB and their assembly is outsourced. There is also the capability to do rework in PCB boards. A small set of mechanical tools allows the production of simple detector prototypes mainly for proofs of concept. In 2019 the e-CRLab had two main activities: the development of MARTA instrumentation and the development of muon hodoscopes. MARTA is a project within the context of Auger to operate RPCs in the Argentine Pampa, under the Auger Water Cherenkov Detectors (WCD). The electronics were developed at e-CRLab that has the responsibility of its operation within the Portuguese participation in the Pierre Auger Observatory. The MARTA front-end electronic, based in the MAROC ASIC, was deployed and the slow control and central unit were developed. Hodoscopes at Auger were developed and are the test-bench for MARTA and used to benchmark other detectors used in Auger. Similar hodoscopes are also being used in the context of SWGO/LATTES and muon tomography for demonstration purposes. The laboratory has also given support to different LIP groups, including the SpaceRad group in the development and production of hardware and to the ATLAS group involved in the development of electronics for the upgrade. A great effort was put towards the HV power supply system for the TileCal. Furthermore, activities are starting on the HTT system of ATLAS, which implies a step further in the laboratory capabilities. The e-CRLab has also been involved in outreach and teaching, namely in the installation of experimental setups at IST for the Advanced Experimental Physics Laboratory and other education activities. These setups focus mainly on the detection of CR and on the study of scintillator detectors.

e-CRLab

Overview

The e-CRLab (electronics for cosmic ray experiments Laboratory) is dedicated mainly to the development of electronics for cosmic ray experiments. The focus is given to 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 do rework in PCB boards. Recently the laboratory has also focused on the development of embedded systems for data acquisition, slow control 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 are composed by an office room, an instrumentation room installed with state-of-the-art equipment and a separate instrumentation room. A small mechanical workshop for detector prototypes development and a dark room are available to complement the activities. The capability to produce PCBs is installed at LIP premises in a separate room. The laboratory counts with two researchers, 1 PhD student and four electronics technicians.

Assessment of the past year: objectives vs. achievements

Unfortunately, the COVID-19 pandemic has had a great impact on the laboratory's activities. To minimize the transmission risk the in-person activities have been reduced to a minimum. Whenever possible we have dedicated more time to the design and system development. Nevertheless, these activities are much more efficient when performed in the laboratory context.

Another impact was the restriction of travels to Argentina. The e-CRLab has a very important role in the development and commissioning of MARTA electronics, which was heavily affected. In this context we have developed the solutions necessary to address the issues found in the field. The interface boards were developed, and the Central Unit has also been developed. The Marta DAQ board is now in a more mature phase. Ricardo Luz has successfully defended his PhD, based on the development of the DAQ system for MARTA.

The setup for the Lousal mine has been built with four planes using the Marta DAQ. The prototype system has been developed by the RPC group using and auxiliary hardware for trigger, synchronization, and readout, pending the availability of the Central Unit. A new hodoscope setup 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 on 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 ATLAS TileCal. Namely the Lab has given a strong support on the development of the HVsupplies board and designed the prototype system interconnect. The e-CRLab was also fundamental to identify and propose solutions for the several test setups and interconnects.

The Infrastructure has opened one position for a technician to work on the ATLAS upgrade, namely on the HTT. It will become an important part of the Portuguese contribution to the experiment that can in this way be done in-kind. The activities are centred in the technical support and management of the production of certain systems but also on the design and operation of the HTT. We are namely studying the interconnect of the systems in HTT using fast ethernet switches.

This year also marked the beginning of a reequipment program. The laboratory has defined as priority the development of capabilities in more complex systems and to improve on the time resolution (and bandwidth) possible to achieve. The acquisition program will allow to expand these capabilities and to have the Infrastructure to give support to the development of performant HW for CERN experiments.

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 into a stable system that can be used in several project as an almost off-the shelf system. The main DAQ board is having a major redesign for two reasons: first it will be necessary to update the FPGA used as part of the system has become obsolete. Furthermore, following the development of Fenix by M. Ferreira, an ethernet adapter for acquisition boards, we will be introducing in the DAQ the possibility of interfacing through ethernet.

On the HV power supply for ATLAS we will consolidate the design and provide support for the production and test of the systems. In terms of the HTT ATLAS upgrade we expect to consolidate our expertise in FPGA for fast signals and to gain expertise of large bandwidth experiments. It seems also necessary to evolve to ATCA systems to explore the full capabilities of such systems.

e-CRLab

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 LIP Coimbra. There is also the will to participate in the development of dosimetry systems for activities related with radiotherapy.

We would also like to explore the development of silicon-based detectors for radiation detection. The main line of work is related to the Space Rad group (we have also been involved in tests of the RADEM monitor) and the possibility to develop systems to be flown. One of the systems could be using COTS components to develop low-cost radiation monitors.

Medium-term (3-5 years) prospects

The e-CRLab infrastructure plans to secure its acquired competences in front-end DAQ and in digital electronics as well as in the system integration. In this period the operation of MARTA and contributions to the muon tomography and SWGO/LATTES will be of key importance. We will pursue a close connection with the RPC group, developing and implementing DAQ systems for other projects within the RPC group. Furthermore, we will also pursue external collaborations. We have already established contacts with groups interested in using systems similar to the developed ones and are contacting OMEGA Circuits to establish a stronger partnership.

The diversification of the Infrastructure's 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 developed solutions in several contexts.

SWOT Analysis

Strengths

The competences acquired in digital logic design, as well as the competence in the design of complex electronic systems. Competence in handling several types of detectors such as RPCs, scintillators coupled to photomultipliers and silicon photomultipliers. Activities developed in the context of research projects. Capability to develop characterization systems. Possibility to plan and perform irradiation campaigns.

Weaknesses

Up to now it was not possible to attract direct funding for the development of detectors. The level of financing is incompatible with the full development of detectors that need an intense level of financing. Publishing of the work developed must be pursued as independent as possible.

Opportunities

The MARTA Engineering array gives the opportunity to lead the development of a medium size project from end-to-end. SWGO/LATTES poses a mid-term opportunity to consolidate activities. The radiation damage studies present the possibility to attract students and financing through the SpaceRad group. Training activities, courses lectured in the e-CRLab and Master theses developed in e-CRLab may allow to increase human power in the laboratory and to pursue different projects. The know-how acquired in the laboratory can also boost the participation in new projects. The investment plan resulting from the FCT evaluation will allow to increase the capability to test-and-measure.

Threats

Financing is always a key issue when developing hardware that needs to invest in service acquisition and materials. Lack of human resources could also be an issue in the mid-term.

RESEARCH INFRASTRUCTURES

LOMaC

Laboratory of optics and scintillating materials

Team Leader:
Agostinho Gomes

Team:
Amélia Maio, João Gentil, Rute Pedro, Luís Gurriana, Luís Seabra

Trainee(s):
Eduardo Batista

Executive Summary

LOMaC was created for the test and preparation of 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 the Dosimetry group and the e-CRLab; radiation hardness studies of TileCal scintillators, focusing on HL-LHC as well as on future detectors; and support for tests of the high voltage boards for the TileCal upgrade. Parallel work on maintenance, upgrades, and reinstallation of LOMaC equipment went on and is expected to continue next year 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 – an automated device to characterize sets of up to 32 optical fibres.
- Mono-fibremeter – an automated device to characterize individual optical fibres.
- Tilemeter – an automated device to characterize scintillators.
- PMT test device – automated testbench 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 SNO+ calibration system.
- WLS fibres for W104/Icarus muon tagger.
- WLS fibres for 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 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 housed 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 and the Dosimetry group.

Assessment of the past year: objectives vs. achievements

The project to develop a prototype of a dosimeter with the sub-millimetric resolution is underway, in a collaboration combining efforts of LOMaC, e-CRLab, and the Dosimetry group. Currently, there are two students (1 Master and 1 PhD in the Dosimetry group) dedicated to this project. A setup for the measurement of the cross-talk of scintillating optical fibers with different cross-sections (1 mm, 0.5 mm, 0.25 mm) was prepared.

The R3B scintillating fibres tracker did not progress but from the contacts with the German teams we got a request from a team of the Technical University of Munich to see if we were able to do the cutting and polishing of 2 mm square scintillating fibres at both sides, for space applications. A small setup was prepared and a set of fibres was polished and sent to Munich for tests and comparison with their polishing method. The preliminary results show that the fibres prepared with the LOMaC technique give the same performance, and the production is much faster and causes lower fibre loss.

Adaptation of the recovered lathe to allow the installation of optical fibre bundles continued and it is almost ready for preliminary tests of optical fibre polishing. The aluminization equipment was transferred from the external building to the new place at the 3Is basement lab, after the end of the installation of the climatization units at 3Is facilities. Based on the LOMaC reequipment plan, new vacuum pumps were bought for the replacement of faulty ones, and maintenance of the old pumps was agreed with UNL. The assembly of the sputtering machine and the associated technical issues will be dealt with as soon as the pandemic conditions allow.

During a large fraction of the year, the working conditions at 3Is labs were very bad due to the ongoing work for the installation of climatization units, since our equipment is very sensitive to dust and power cuts, and appreciable amounts of dust were generated during the several phases of the installation of pipes and other climatization equipment. The fibremeter was kept at

FCUL, where the working conditions were better (cleaner), and it helps to attract students (like the ones that are now working in dosimetry).

The PMT testbench upgrade work was limited to the repair of the LED driver for light pulses generation, to allow its usage in the tests of the new TileCal High Voltage system. The testbench PC motherboard got damaged probably due to a power cut and needed to be replaced near the end of the year.

In the framework of the ATLAS/TileCal, it was 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 and new studies may help to assess radiation damage of the TileCal optics and help also in the development of new radiation hard scintillators for future detectors.

LOMaC's contribution to education and outreach this year was constrained by the pandemic situation. During the LIP Internship Program, two students have worked at LOMaC for their projects. One focused on the TileCal upgrades and studied the natural aging of the plastic fluorescent materials used in the construction of TileCal. The other one continued the work started by a former Master student within the collaboration with the LIP Dosimetry group, and the experimental aim was the measurement of cross-talk using a dedicated setup where fibres are juxtaposed.

Lines of work and objectives for next year

For 2021, a boost in the facilities is expected, with the progress in the reequipment program that is oriented to the refurbishment of the fibre cutting and aluminization facilities and the testbenches at level of light detection and data taking.

The most relevant facilities will become operational. The lathe associated setup will be finished and tested polishing sets of plastic optical fibres. The assembly of the sputtering machine will be concluded: maintenance of pumps, cleaning bellows, mounting pumps, target and make the first tests at the new location. All these technical issues will be dealt with as soon as the pandemic restrictions allow. The aluminization setup will become ready for the production of aluminized bundles of fibres and other applications that may fit in this setup.

The tilemeter will be improved, with the replacement of the old PMTs by new photodetectors. A new hodoscope for measurement of number of photoelectrons in scintillating fibres will be setup. We intend also to continue the upgrade of the PMT testbench, and use it in tests of the new TileCal High Voltage system. Ageing studies of TileCal optics focusing on scintillators and fibres are planned, and the possibility of production of radiation hard scintillators in partnership with Univ. Minho will be explored. The collaboration with the LIP Dosimetry Group and e-CRLab will continue for the readout and characterization of scintillating optical fibres for applications in microdosimetry.

Medium-term (3-5 years) prospects

In the medium term, LOMaC contributions will focus on three areas. The first one is the Tile calorimeter of ATLAS and associated detectors. There will be work in the search for radiation hard scintillators and WLS fibres for the future replacement of the gap/crack scintillators for the HL-LHC runs. At the same time, there will be an effort to better estimate the degradation of the main scintillators and WLS fibres of TileCal.

The second area is to contribute to the studies for scintillator-based detectors for the Future Circular Collider (FCC). Studies using scintillators, WLS fibers, and several photodetectors will be done.

The third area corresponds to applications in microdosimetry, where the characterization of scintillating optical fibres is foreseen, in close collaboration with the LIP Dosimetry Group.

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

Ageing 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 hadron 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.

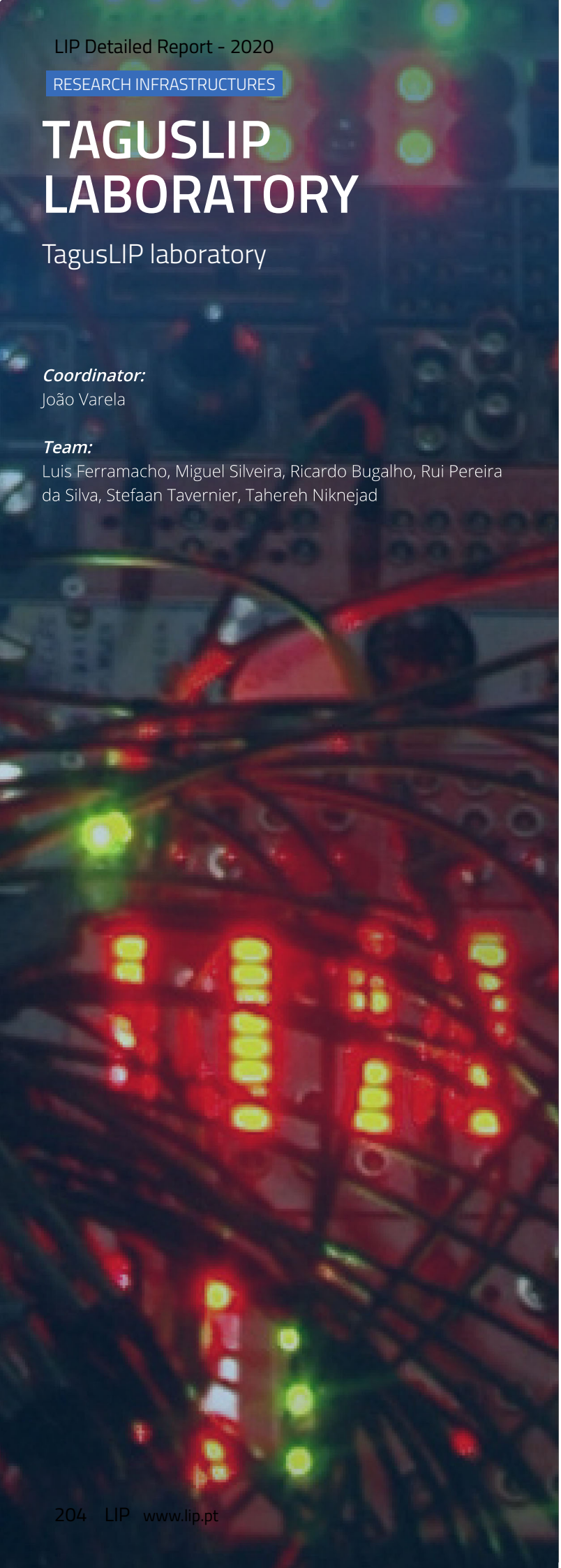
RESEARCH INFRASTRUCTURES

TAGUSLIP LABORATORY

TagusLIP laboratory

Coordinator:
João Varela

Team:
Luis Ferramacho, Miguel Silveira, Ricardo Bugalho, Rui Pereira da Silva, Stefaan Tavernier, Tahereh Niknejad



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 laboratory

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 PME's.

TagusLIP was conceived as a generic infrastructure for the development of radiation detectors in the areas of PET imaging and experimental particle physics. TagusLIP includes detector and electronics laboratories, electronics workshop, 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. The TagusLIP has a computing and data storage infrastructure, suitable to software projects in various areas, such as data acquisition, equipment control, data analysis and image processing. The TagusLIP is licensed for the use of radiation sources needed to develop and test new instruments in nuclear medicine.

The research teams that traditionally have been using TagusLIP have large experience in the development, commissioning and operation of large detectors in Particle Physics experiments and medical instruments. The LIP-CMS group has developed and installed the Data Acquisition System of the Electromagnetic Calorimeter of the CMS experiment. TagusLIP was home to the integration and commissioning of two PET scanners dedicated to mammography developed by the national PET-Mammography Consortium led by LIP in the framework of the Crystal Clear Collaboration at CERN. The LIP group Spinoff Technologies for Cancer Detection (STCD) developed long experience in the design and implementation of detector readout ASICs, in particular the ClearPEM ASIC for APD readout, and the TOFPET1 ASIC for Time-of-Flight applications with SiPMs developed in the framework of the EU project EndoTOFPET-US. In synergy with the STCD group, the LIP-CMS group developed the TOFEE ASIC for the readout of LGAD fast silicon sensors for the CT-PPS proton spectrometer in collaboration with INFN/Torino.

The development of TOFPET1 ASICs for PET Time-of-Flight applications was at the origin of the creation of the start-up company PETsys Electronics in 2013. The shareholders of PETsys Electronics are the venture capital company Portugal Ventures, several institutional shareholders of the mother company PETsys Systems including LIP and other institutional partners of the PET-Mammography Consortium, as well as individual collaborators. A technology transfer contract between LIP and PETsys Electronics included in the process of creation of the company transferred the TOFPET1 IP from LIP to PETsys Electronics. The company PETsys Electronics has been using the TagusLIP infrastructure under the terms of a protocol established with LIP. The TagusLIP operation costs are presently shared between LIP and PETsysElectronics.

Benefiting from the infrastructure available at TagusLIP, PETsys Electronics was able in the past 7 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 2020 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 prototype TOFHIR2A showed excellent performance matching the simulation expectations. A batch of TOFHIR2 boards was produced, tested and made available to several groups in the CMD/MTD collaboration.
2. Successful validation of the first prototype of the BTL Front-End Board integrating six TOFHIR1 ASICs.

PETsys Electronics

1. Characterization of the performance of the ASIC TOFPET2 for special applications as requested by costumers.
2. Organization of the production, testing and supply of PETsys Electronics products.
3. Microelectronics design of the TOFHIR2 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 first version of the chip was designed (TOFHIR2A) and the second version with improved performance was submitted for fabrication in November 2020 (TOFHIR2X)

4. In collaboration with the PANDA experiment at the future Facility for Antiproton and Ion Research (FAIR), development of a full readout system based on the PETsys Electronics TOFPET2 ASIC. The final detector will consist of 28,800 channels.

5. Leadership of the consortium Time-of-Flight PET for Proton Therapy (TPPT) and development of the readout system.

The results obtained were presented at several international conferences, including IEEE/NSS/MIC 2020 (online conference).

Lines of work and objectives next year

The LIP-CMS group and the company PETsys Electronics will be the main users of the TagusLIP Laboratory in 2021.

LIP-CMS group

The R&D activities in the CMS Barrel Timing Detector (BTL) planed by the LIP-CMS group are described elsewhere in this report and summarised here:

1. Tests of the second prototype of the BTL Front-End board (FE_v2) with the TOFHIR2X ASIC, and integration in the BTL Readout Unit. Tests with sensor modules are foreseen at TagusLIP and CERN.
2. Test of the new ASIC version TOFHIR2X designed by PETsys Electronics. Integration with detector modules based on LYSO crystals and SiPMs and characterization with laser light and radioactive sources.
3. Development of prototypes of timing detectors for the future PPS detector at HL-LHC in synergy with the MTD project.
4. Development in collaboration with PETsys Electronics and Amplification Technologies (USA) of "Intelligent Sensor for LIDAR Applications" (proposal submitted to FCT).

PETsys Electronics

The activities of PETsys Electronics in 2020 include:

1. Tests of components and systems supplied by PETsys Electronics.
2. To pursue the development of the dedicated frontend electronics for the PANDA experiment, as well as dedicated systems for several clients.
3. Design of the final version of the ASIC TOFHIR2 (TOFHIR2B). Submission is planned in Q2 2021.
4. 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.
5. Development of an improved version of the TOFPET ASIC (TOFPET3) and of a prototype ASIC for LIDAR (TOFLAR).

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 CENTRES

CCMC

Competence Center in Monitoring and Control

Coordinator:
Francisco Neves

2 ***Researcher(s):***
Filipe Veloso, Helmut Wolters

1 ***Technician(s):***
João Carlos Silva

1 ***Master Student(s):***
João Parente

3 ***Trainee(s):***
Francisco Casalinho, Joana Mota, Matilde Simões

Executive summary

The main purpose of the Competence Centre 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 latter, another key objective of the CCMC concerns the training of human resources and the development of outreach instruments.

CCMC

Overview

The Competence Centre in Monitoring and Control (CCMC) is a small horizontal LIP infrastructure consisting basically of human resources scattered among different fields of activities: from low energy and rare event searches to high energy particle physics and computing. This diversity is key to fulfill its main objective of gathering different expertise from different backgrounds and areas of scientific research.

The group activities are focused on the design, development and coordination of user-specific solutions for monitoring and control including all required software tools, usually delegating the manufacturing of electronics and other hardware to the LIP electronics and mechanical workshops. Besides the hardware and respective firmware, the group also develops analysis tools required to extract information from the data being collected. The workload is usually divided among the CCMC members according to their availability and dedication to their scientific projects.

Assessment of the past year: objectives vs. achievements

During 2020, the CCMC achievements include:

1. Production of a new batch of 25 heart rate and temperature monitors for nesting birds ordered by the ECOTOP group of the University of Coimbra. The new devices feature important improvements in both the hardware and firmware, allowing to extend the recording time and eliminate data acquisition dead-times. This task was not initially planned but was a successful follow up of the work completed also during 2020 concerning the production, testing and deployment in field conditions of a first batch of two units for the same group;

2. The work to develop and build a device to control and monitor ambient parameters of nests installed in the natural habitat of birds (aiming at studying potential effects of the temperature increase associated with climate change) for the ECOTOP group, was not carried out due to the lack of funding, However, both the CCMC and the ECOTOP group are actively searching for alternate funding (currently applying together to FCT funding);

3. The work on the CCMC end-user software framework continued in collaboration with the LZ LIP group. Although not initially planned, this collaboration intends to integrate a Graphical User Interface (GUI) developed by the LZ team with the database tools being developed within the CCMC, therefore benefiting both parts;

4. The environment monitoring system planned for the server room at LIP-Coimbra was not installed due to the lack of human resources;

5. Although not initially planned, the CCMC participated in a month-long Summer Internship program for university-level students with the project “Observação de Muões Cósmicos” at the Physics Department of the University of Coimbra;

6. All other planned outreach activities were canceled due to the COVID-19 pandemic.

Lines of work and objectives for next year

The main CCMC objectives for 2021 are:

1. Together with the ECOTOP group of the University of Coimbra, develop and build a device to control and monitor ambient parameters (e.g temperature, pressure, sound, image) of nests installed in the natural habitat of birds. This work aims at studying potential effects of the temperature increase associated with climate changes in the nesting behaviour of birds. The participation of the CCMC in this project also extends to the development of the analysis tools to extract the relevant parameters from the acquired data. This project is currently running for FCT funding and includes:
    1. The allocation of a Master student scholarship for the CCMC analysis tasks;
    2. Participation in outreach and dissemination activities related to the project;
2. 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;
3. Install an environmental (e.g. temperatures) and computer (e.g. CPU load) monitoring system for the server room at LIP-Coimbra. This work will also serve as a production test for the software framework described above and will include a LIP intranet webpage for visualization of the environment conditions, management of alarms, etc.;
4. Upgrade the analysis tools for the temperature and heart rate monitors built for the ECOTOP group. The planned work aims at improving the precision of the heart rate calculation taking advantage of the new firmware mentioned earlier;
5. Congregate efforts for the development of outreach hardware with the LIP ECO group, namely: update the existing cloud chamber firmware and implement a new real-time track analysis software for demonstration purposes;

CCMC

update the existing atmospheric balloons with muon-counter position monitoring system. The group plans to apply for funding for this task.

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 the creation of a portfolio and the realization of workshops for the dissemination of the CCMC capabilities. The engagement with new projects is strongly dependent on the opportunities which may arise from that.

SWOT analysis

Strengths

1. A large body of knowledge accumulated from the participation of LIP members in several experiments, often with direct responsibilities in the development, construction and maintenance of monitoring and control subsystems.

Weaknesses

1. Do not have (explicitly) allocated FTEs or resources for the procurement and project development and integration with the other LIP infrastructures.
2. The current inability to certificate products and services.

Opportunities

1. The ability to deploy very high quality products and services developed within scientific projects and meeting very high quality and reliability standards.

Threats

1. The need to meet deadlines and ensure the human power required for the assistance to services/products contracted with third party entities.
2. The lockdowns established to hold down the COVID-19 pandemic may result in difficulties reaching potential new clients.

Publications

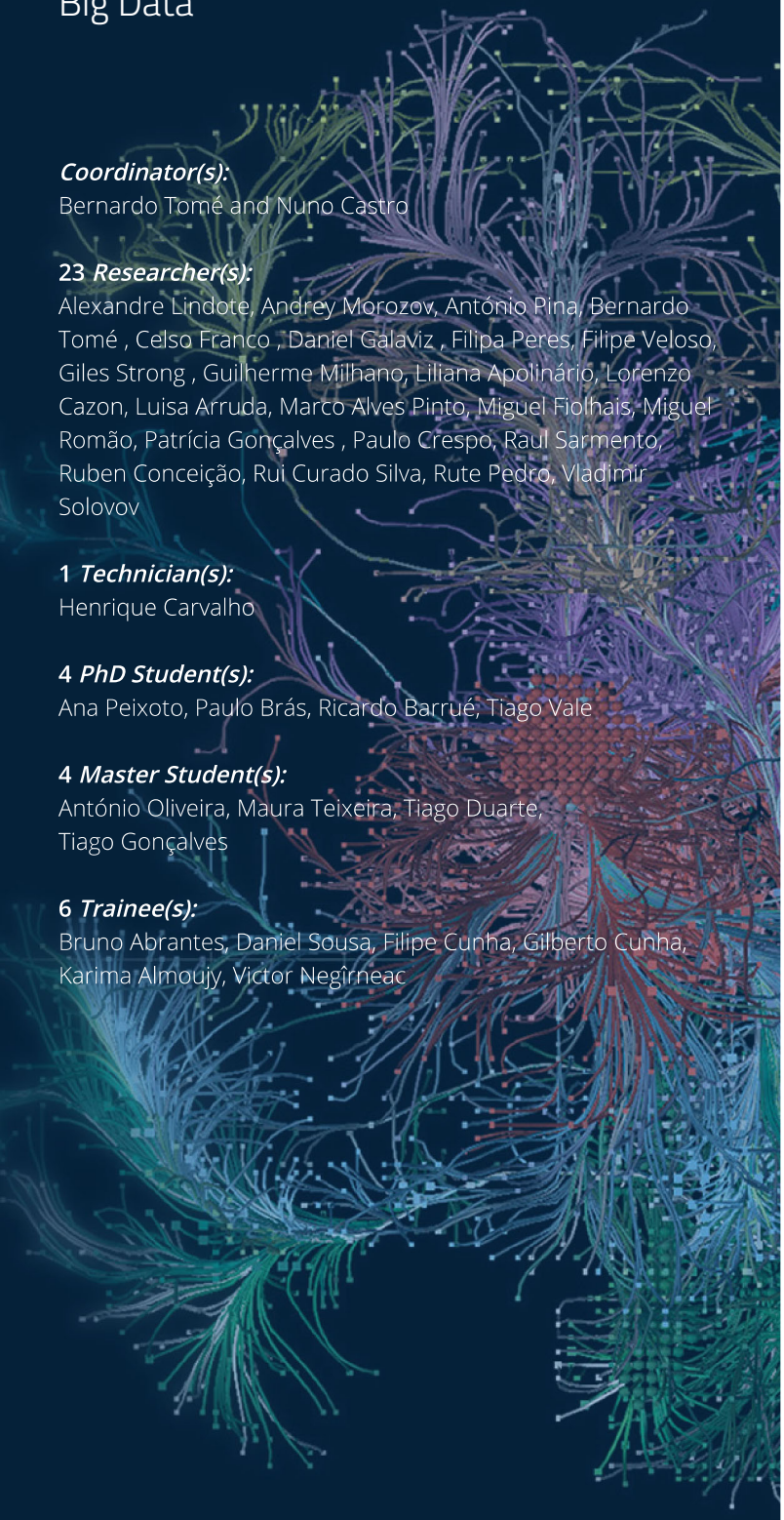
1 LIP Students Notes

- *Joana Mota, Matilde Simões, Francisco Casalinho: "Observação de muões cósmicos", LIP-STUDENTS-20-21*

COMPETENCE CENTRES

SIMULATION & BIG DATA

Competence Centre on Simulation and Big Data



Coordinator(s):
Bernardo Tomé and Nuno Castro

23 ***Researcher(s):***
Alexandre Lindote, Andrey Morozov, António Pina, Bernardo Tomé , Celso Franco , Daniel Galaviz , Filipa Peres, Filipe Veloso, Giles Strong , Guilherme Milhano, Liliana Apolinário, Lorenzo Cazon, Luisa Arruda, Marco Alves Pinto, Miguel Fiolhais, Miguel Romão, Patrícia Gonçalves , Paulo Crespo, Raul Sarmento, Ruben Conceição, Rui Curado Silva, Rute Pedro, Vladimir Solovov

1 ***Technician(s):***
Henrique Carvalho

4 ***PhD Student(s):***
Ana Peixoto, Paulo Brás, Ricardo Barrué, Tiago Vale

4 ***Master Student(s):***
António Oliveira, Maura Teixeira, Tiago Duarte, Tiago Gonçalves

6 ***Trainee(s):***
Bruno Abrantes, Daniel Sousa, Filipe Cunha, Gilberto Cunha, Karima Almoujy, Victor Negîrneac

Executive summary

The purpose of the Competence Centre 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 competence centre started its activities almost three years ago, with a significant boost since 2019 when dedicated human resources were hired through a funded project. The current challenge is the consolidation of the Competence Centre, focusing on selected areas where we can be competitive. For the simulation part, the specific contributions to the GEANT4 collaboration should be continued and expanded, while in the Big Data part, the team is consolidating the experience on anomaly detection techniques in experimental context, 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 Centre, as well as sharing this expertise within LIP and beyond.

Simulation & Big Data

Overview

The Simulation branch of the competence centre developed the following activities:

- Teaching of advanced detector simulation techniques as part of the curricula of specific undergraduate courses and doctoral programs.
- Participation in the GEANT4 collaboration was continued. Support and maintenance of one Advanced Example for which LIP has been responsible was followed, namely in view of the last GEANT4 release in December 2020.
- Support to the needs of LIP research groups was maintained.
- An introductory course on GEANT4 was held in February 2020 at the University of Minho (Braga).

The Big-Data branch of the competence centre developed the following activities:

- Study and development of machine learning techniques for the detection of rare events at colliders, resulting in 4 publications, 1 completed Master thesis (2 ongoing), 5 ongoing PhD theses and several presentations 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 but postponed to 2021 due to the pandemic.
- Established a partnership with Tellspec, in the context of the analysis of data collected with portable infrared spectrometers and possible applications in quality control for production lines.
- Ongoing collaborations between members of different LIP groups (ATLAS, CMS, Auger, LATTES, Dark Matter, Phenomenology, SHiP) in the context of machine learning, including providing dedicated computing resources.
- Collaboration with the gravitational waves community in the context of machine learning through the COST action CA17137 (started in September 2018).

Assessment of the past year: objectives vs. achievements

On the Simulation side, several developments were undertaken in the context of the specific activities of the LIP groups:

- The planned features related to the ANTS2 general-purpose front-end were implemented. Simulations in ANTS2 can be configured using an interactive graphical interface and then delegate particle tracking to Geant4.
- A method to implement geological topographic maps into Geant4 started being developed. This is expected to improve the accuracy of Muon Tomography applications namely at the Lousal mine. Other applications include Space exploration and Astrobiology where accurate calculation of radiation levels is critical.
- The iAstro group developed a simulation model to estimate AMEGO-X mission polarimetic performance, using the Geant4-based simulation tool MEGAlib. The iAstro group developed also a simulation of the AHEAD2020 COMCUBE demonstrator. The first version of the simulation mass model of the STRATOSPOLCA ESA Balloon experiment was also implemented using MEGAlib.
- The NUC-RIA group developed a set of generators for the simulation of the main sources of the environmental background. This code has been developed within the EnsarRoot framework, which uses Virtual MonteCarlo platform and Geant4 as a transport engine. Response functions and efficiency of Silicon Drift Detectors for X-ray detection, in the context of the measurement of the 118Sn(p,γ)119Sb reaction cross, have been simulated using Geant4.
- Planned editions of the Geant4 introductory course were postponed due to the limitations imposed by the pandemic.

On the Big Data side, the ongoing funded projects allowed to expand the LIP competences in machine learning, as well as to hire dedicated human resources through contracts and grants. This was an objective for 2020 and it was largely achieved, allowing to make some relevant advances in the development of anomaly detection techniques (Autoencoders, Isolation Forest, Histogram Based Outlier Detection, and Deep Support Vector Data). The pandemic situation led to some decrease on the interactions between groups, but the remote contact was maintained as much as possible, as well as the sharing of available resources and the dissemination of results in workshops and conferences. One MSc thesis was concluded, three PhD thesis are close to completion and new students were engaged in the activities of the competence center.

Simulation & Big Data

The third edition of the Data Science School and Symposium was planned to be organized in March 2020 in Coimbra but had to be postponed to 2021 due to the pandemic. A new collaboration with Tellspec (https://tellspec.com/) a company performing chemical analysis in the field of food quality and medical specimens was established. This collaboration is a direct consequence of the training program of the Competence Center, since a former MSc student, who graduated in 2019, joined this company shortly after leaving LIP and acted as a liaison to the Competence Center. In 2020 we have applied to a new project under the FCT call for all scientific domains and despite a very positive review by the jury we weren't recommended for funding. A new proposal is being prepared, focusing on anomaly detection techniques. Some of the team members succeeded in their application to CPU and GPU hours in a national call for access to scientific computing clusters.

Lines of work and objectives for next year

The Simulation branch of the competence centre will continue its contribution to the teaching of advanced detector-simulation methods in 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. Developments in the context of the specific activities of LIP groups are also planned. In the framework of AMEGO proposal, the i-Astro group will contribute to the MEGAlib simulation model of a small size prototype experiment scheduled to be performed at the Duke University beamline. The NUC-RIA group has planned several simulation developments using GEANT4, namely of: the emission of photons in proton-induced reactions (PIGE); response of the calorimeter CALIFA to high-energy photons; detection of high-energy neutrons by Boron-coated RPCs (in collaboration with LIP-Coimbra). The second edition of the GEANT4 Introductory courses is foreseen to be held by the end of 2021, likely in Coimbra if a presential format will be possible. Nevertheless given the uncertainty driven by the present situation, its exact format will be assessed later.

In what concerns the Big Data part of the Competence Centre, 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 Centre are being used in the search for new physics events at ATLAS and the search for rare events in LZ/LUX. This dissemination of the 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.

Medium-term (3-5 years) prospects

The medium-term strategy of the Simulation and Big Data Competence Centre 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 Competence Centre should have its activities consolidated, following the plan defined at its creation, more than two years ago: expand LIP's competences in this area by exploiting synergies between the different groups, implement a training program and establish partnerships with the academic and industrial communities interested in this field. The foreseen opportunities in terms of digital society and digital transformation will be explored.

SWOT analysis

Strengths

- Longstanding expertise in simulation and big data at LIP.
- Expertise in modern data mining techniques used in HEP and beyond.
- Integration in international collaborations (HEP experiments, GEANT4 collaboration).
- Diverse team, consolidated by competitive fundings secured by the Competence Centre.

Weaknesses

- Despite some progress in the last years, the different 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.

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).
- The implementation of a 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 to recruit new PhD students developing work in simulation and big data.

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.

Simulation & Big Data

Publications

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

- *"Transferability of Deep Learning Models in Searches for New Physics at Colliders"*, M. Crispim Romao, N. F. Castro, R. Pedro, T. Vale, Phys. Rev. D 101 (2020) 035042
- *"Study of interference effects in the search for flavour-changing neutral current interactions involving the top quark and a photon or a Z boson at the LHC"*, Maura Barros, Nuno Filipe Castro, Johannes Erdmann, Gregor Gebner, Kevin Kroninger, Salvatore La Cagnina, Ana Peixoto, Eur. Phys. J. Plus 135 (2020) 339
- *"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

1 Article(s) in national journal(s)

- *"Medida da atenuação de raios cósmicos num edifício"*, Nuno Castro, José Alves, Raul Sarmento, Gazeta de Física 43 (2020) 2

Presentations

1 Presentations in national conferences

- Rute Pedro: *"Machine Learning na Física de Altas Energias"*, 2020-09-03, Física 2020 22ª Conferência Nacional de Física, Sessão Paralela "Astronomia, Astrofísica e Física de Partículas, Lisboa

4 Oral presentations in national or international meetings

- Rute Pedro: *"Full Event Distances"*, 2020-05-18, Anomaly Detection Forum, CERN
- Rute Pedro: *"Methods for Anomaly Detection in Collider Searches"*, 2020-06-15, Anomaly Detection Forum, CERN
- Miguel Romão: *"Deep Learning as a Tool for Generic Searches at Colliders"*, 2020-07-07, IML Machine Learning Working Group Meeting, CERN, Geneva
- Rute Pedro: *"Deep Learning as a tool for Generic searches at Colliders"*, 2020-07-16, Mini-Workshop Anomaly Detection LHC Olympics, Virtual World - Berlim

Theses

5 PhD

- João Marcos: *"Real-time statistical event reconstruction for medical scintillation cameras"*, 2015-01-01 / 2020-06-12, (finished)
- Paulo Brás: *"New physics phenomenology and data processing tools for the LZ experiment"*, 2016-01-01 / 2021-02-24, (finished)
- Ana Peixoto: *"Search for FCNC in tZ trilepton events at the ATLAS experiment"*, 2016-09-13, (ongoing)
- Tiago Vale: *"Search for vector-like quarks in Zt/b+X events at ATLAS"*, 2016-09-13, (ongoing)
- Guilherme Guedes: *"Collider and astrophysical constraints to little Higgs models"*, 2018-11-13, (ongoing)

4 Master

- Maura Teixeira: *"Search for Dark Matter in Monotop Events at the Large Hadron Collider"*, 2018-10-01 / 2020-11-19, (finished)
- Tiago Duarte: *"Treino de redes neuronais profundas de forma distribuída"*, 2018-10-01, (ongoing)
- Tiago Gonçalves: *"Estudo do modelo de computação HPX e da respetiva plataforma de execução"*, 2019-10-01, (ongoing)
- António Oliveira: *"Unsupervised machine learning techniques in high energy physics"*, 2020-09-08, (ongoing)

Organized Events

1 Collaboration Meetings

- *"2nd general meeting of the BigDataHEP project"*, [Coll-Mtg] ID: 339, 2020-02-13 / 2020-02-13, Braga

1 Advanced Training Event

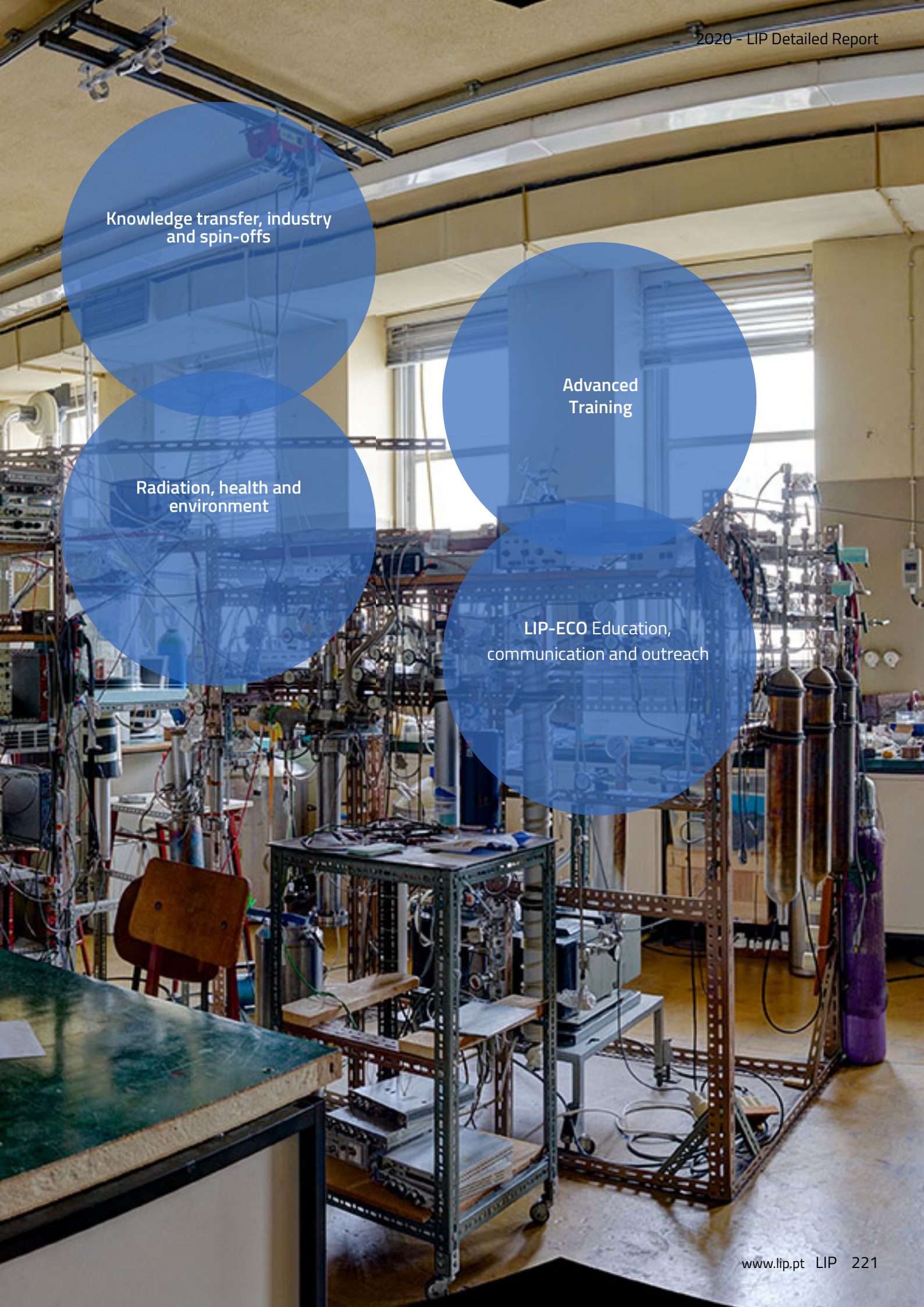
- *"LIP introductory course on Geant4"*, [Coll-Mtg], 2020-02-11 / 2020-02-13, University of Minho, Gualtar Campus, Braga

Sources of funding

PI	Code	Amount	Dates	Description
Nuno Castro	PTDC/FIS-PAR/29147/2017, POCI/01-0145-FEDER-029147	239.990 €	2018-07-01 / 2021-06-30	BigDataHEP: Understanding Big Data in High Energy Physics: finding a needle in many haystacks

Total: 239.990 €

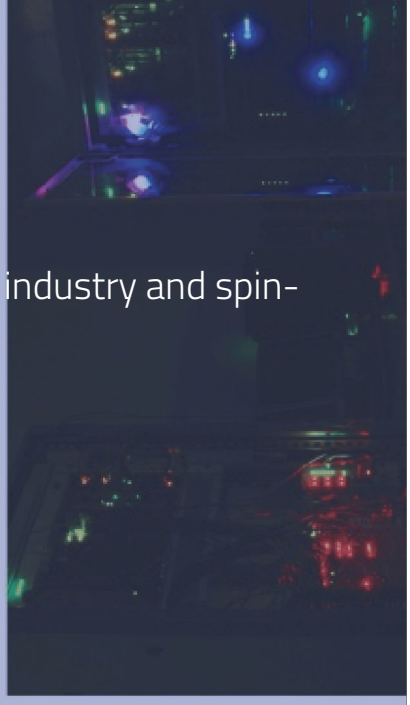
Science and Society

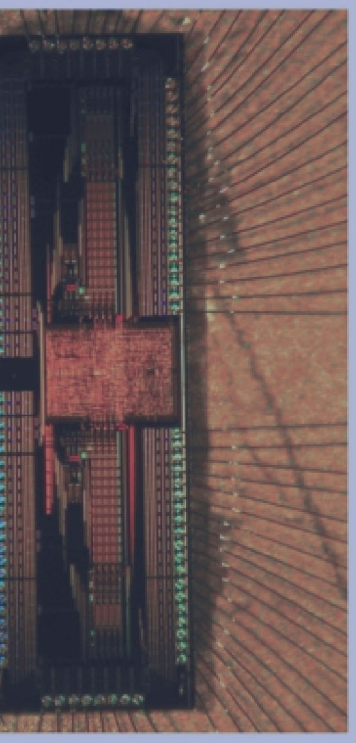

Knowledge transfer, industry and spin-offs
Advanced Training
Radiation, health and environment
LIP-ECO Education, communication and outreach

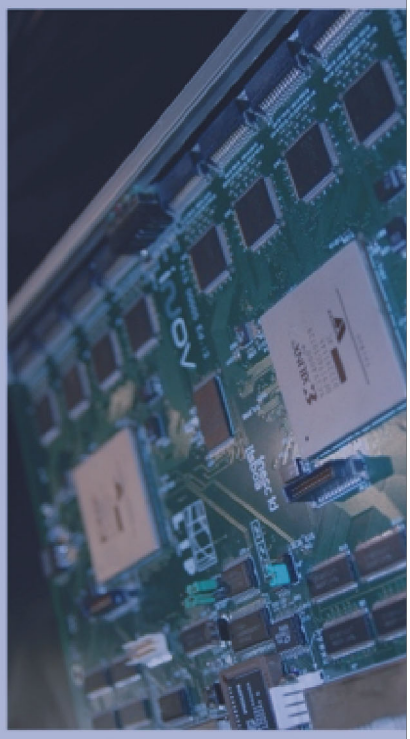
SCIENCE AND SOCIETY

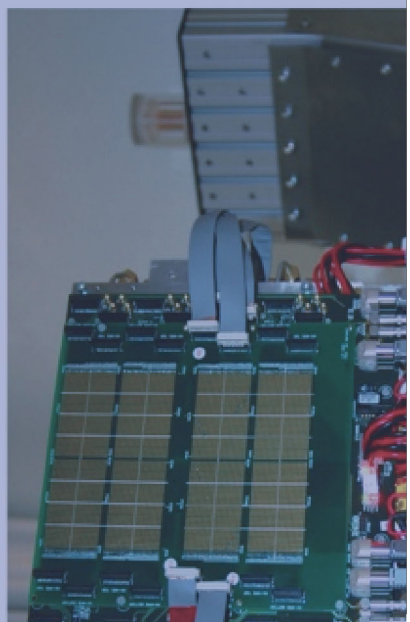
KT

Knowledge Transfer, industry and spin-offs









KT

Overview

LIP is engaged on 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.

In the coming years such public policy objectives will be pursued and supported by LIP structures: research infrastructures (detectors and electronics laboratories and workshops, computing infrastructures); Competence Centres (namely, Simulation and Big Data, as well as Monitoring and Control); Advanced Training and Education and Outreach groups; Knowledge transfer (KT) group. 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.

Aspects that are key to LIP's societal role are highlighted below.

Articulation of the scientific infrastructures included in the National Roadmap for Research Infrastructures 2020 approved by FCT

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).

Collaborative and innovation projects

The list of companies the LIP groups have collaborated with in the last 5 years includes Adductio, Bosch, Cabelte, Dialog Semiconductors, EFACEC, EVOELEO, Grupo ASSEC, HIDRONAV (Spain), ICNAS-Produção, Ideas (Norway), Kinetic (UK), Nielsen, NuRise, PETsys, Siemens, Silicon Gate, Systion, Tellspec and Wavecom. Some of the main Portuguese research units and other public institutions we collaborated were CEFITEC/NOVA, 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).

The main role in KT processes will be played by the KT group, which will 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 (within the management and administration services), and designate a contact person for KT at LIP. Competence centres also play an important role in this strategy and their scope will be enlarged. Furthermore, 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.

Internationalization of Portuguese companies

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.

Digital competences and technologies

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 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.

Training for employability and qualification

Directly involve graduate students in collaborative, multidisciplinary, innovation projects with companies and other external entities, through internships, technology-oriented advanced training and the inclusion of an applied research component in their projects. This will enhance their level of employability in the private sector and contribute to increase the qualification of the human resources in Portuguese companies.

Portuguese traineeship programme at CERN: Since several years LIP supports the FCT programme "Advanced training of engineers in the International Organizations - CERN, ESA and ESO". Since 2017, the programme was split into two calls, one for CERN and the other for ESA and ESO, with LIP supporting the CERN call. LIP encourages the groups at CERN to prepare and submit job description proposals (with a priority for the participation of Portuguese institutions and/or in key areas of interest to Portugal, as defined by FCT), helps disseminate the calls, particularly through our networks and partner universities and participates in the selection process of the candidates. A very positive feedback from the supervisors is testimony to the importance and success of this programme.

RESEARCH / SCIENCE AND SOCIETY

RADIATION, HEALTH AND ENVIRONMENT

Radiation, health and environment

Principal Investigator:
Luis Peralta (30)

4 ***Researcher(s):***
Alina Louro (10), Conceição Abreu (30), Florbela Rêgo (10), Sandra Soares (80)

3 ***PhD Student(s):***
Joaquim Pedro Kessongo (100), Margarida Isabel Inácio (100), Yoenls Bahu (100)

1 ***External/Additional scientific collaborator(s):***
Patrick Sousa

Total FTE:
4.6

Executive summary

The main activities of the group are radon measurements and studies of radon effects. Radon is a radioactive gas present in the atmosphere, both indoor and outdoor. The main threat posed by radon is the induction of lung cancer, although other effects are under study. The group has been involved in radon surveys in Portugal (in the Guarda district) and Angola (in Bíbala and Huíla districts). Radon concentration in water and in air have been measured. The radon exhalation from Portuguese construction granite have also been evaluated.

Article(s) in international journals:	**4** Direct contributions **1** Indirect contribution
Article(s) in national journal(s):	**1**

Radiation, health and environment

Overview

The group main laboratory for the radon study is the LabExpoRad. The facility is integrated in UBIMedical, the University of Beira Interior health technology park. The laboratory is equipped for the detection of radon in water and air. In the past few years the work focus was on the measurement of radon in the air and water in Angola and the study of radon exhalation from building materials.

Assessment of the past year: objectives vs. achievements

Radon measurements

The exposure to radon in buildings in the municipality of Lubango, Angola, during winter months was done and the data analyzed. As far as we know, the evaluation of indoor radon exposure in dwellings, was done for the first time in Lubango. The corresponding annual effective dose to which the population is exposed during the wintertime was calculated. A total of 59 single-family houses and 16 public buildings were selected. The results obtained show that in 63% of the houses, the radon concentration exceeds 100 Bq m^{-3}, the reference level recommended by the World Health Organization. The values of the indoor annual effective dose vary from 2.0 to 7.0 mSv/year below the recommended maximum reference level of 10 mSv/year.

Radon exhalation

Radon concentration can reach high levels in dwellings depending not only on exhalation from soil but also on the building material used like concrete, bricks, phosphogypsum or granite. In general, either to improve waterproofness or indoor performance namely comfort and disintegregation of the natural stone limiting the particle loss, some coatings are normally used over natural stone. Radon mass exhalation rate is one of the parameters commonly used to express indoor radon released from building and ornamental materials. This quantity can be obtained from the radon concentration in air. The measurement techniques are thus derived from the ones used for radon concentration measurement. In this work the used measuring technique was the 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. Passive or active detectors can be employed for this task. The final result is affected by chamber leakage. In order to assess the radon leakage a chamber was prepared to measure the radon concentration in real time. From these measurements we concluded that the leakage rate depends on the radon concentration inside the chamber.

Effect of aerosols

The study of the effect of aerosols containing radon on the development of aromatic plants will continue. Some experimental work has been done, but more data is needed, since preliminary tests yield inconclusive results.

Some of the activities during 2020 were affected by the COVID-19 pandemic. The collaboration with the Informatics Engineering Department and the Town Hall of Fundão was delayed. Also the study of the effect of aerosols containing radon on the development of aromatic plants had to be postponed. However the MERADE 2 training school took place.

Lines of work and objectives for next year

1. The Collaboration with the Informatics Engineering Department and the Town Hall of Fundão to develop and build an IoT ecosystem in smart home environments is about to start. It will integrate and use a number of wireless sensors, such as humidity, temperature, CO, CO2 and radon gas, to detect, predict and evacuate the radon gas from buildings.

2. More tests on the effect of aerosols containing radon on the development of aromatic plants are under way. The objective is to analyze the effects and potential consequences on the biological development of aromatic plants exposed to different concentrations of radon. We also intend to analyze the biological effects of polluting atmospheres, with different concentrations of radon, 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.

3. 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.

Medium-term (3-5 years) prospects

1. Strengthen the institutional relation with Agência Portuguesa do Ambiente (Portuguese Environmental Agency).

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. Participation in a project in partnership with the Portuguese Lung Foundation for the assessment of radon exposure of patients with adenocarcinomas.

4. 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 saturated atmospheres with radon gas.

SWOT Analysis

Strengths

Well equipped laboratory.

Weaknesses

Small team.

Opportunities

Collaboration with other national and international institutions and laboratories.

Threats

Lack of solid funding.

Radiation, health and environment

Publications

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

- *"Development of a low-cost monitor for radon detection in air"*, Soraia Elisio, Luis Peralta, Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 969 (2020) 164033
- *"Radon concentration potential in Bibala municipality water: Consequences for public consumption"*, Joaquim Kessongo, Yoenls Bahu, Margarida Inacio, Luis Peralta, Sandra Soares, Radiat. Phys. Chem. 173 (2020) 108951
- *"Comparison of Radon Mass Exhalation Rate Measurements from Building Materials by two Different Methods"*, Sandra Soares, Joaquim Kessongo, Yoenls Bahu and Luis Peralta, Radiation Protection Dosimetry (2020), Vol. 191, No. 2, pp. 255–259
- *"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

1 Article(s) in national journal(s)

- *"Proteção contra a radiação ultravioleta fornecida por óculos de sol "*, Luis Peralta, Revista Brasileira de Ensino de Física, vol. 42, e20200144 (2020)

Theses

2 PhD

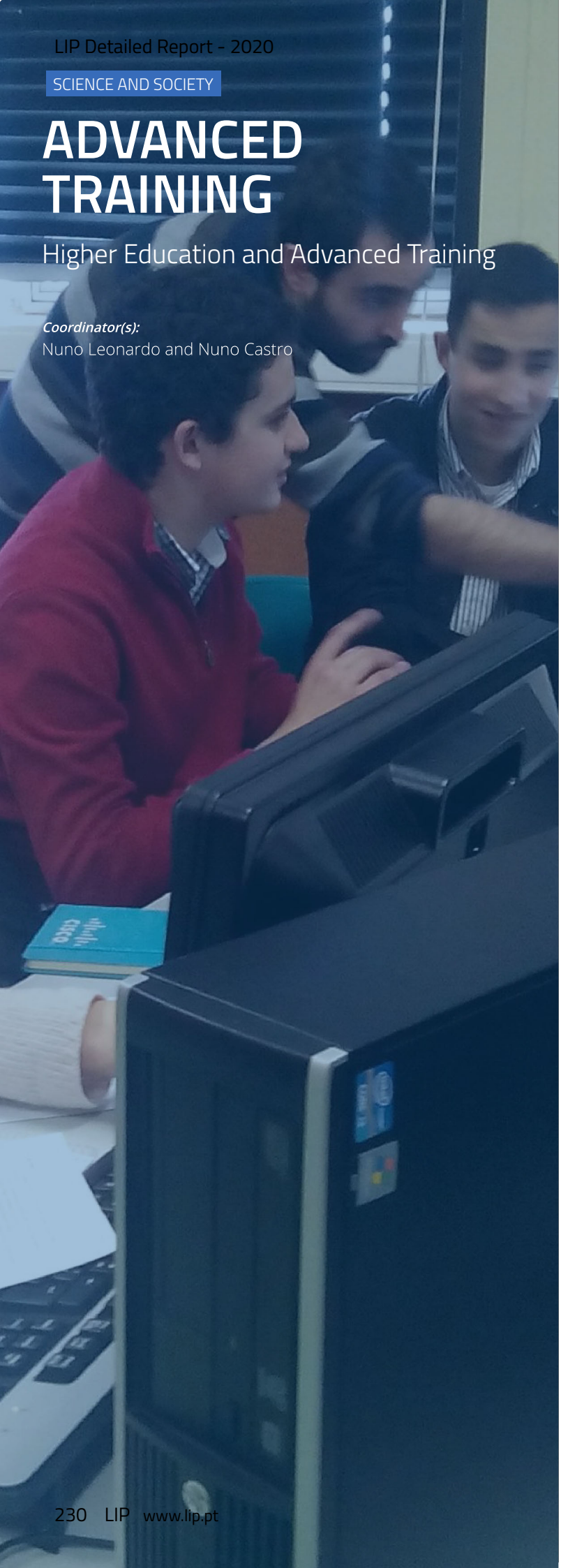
- Yoenls Bahu: *"Avaliação do Potencial de Exposição ao Radão em Edifícios Públicos no Município do Lubango"*, 2016-11-01, (ongoing)
- Joaquim Pedro Kessongo: *"O Potencial da Concentração de Radão na Água do Município da Humpata-Angola: Implicações no Consumo Público"*, 2016-11-01, (ongoing)

SCIENCE AND SOCIETY

ADVANCED TRAINING

Higher Education and Advanced Training

Coordinator(s):
Nuno Leonardo and Nuno Castro



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 PhD, master and bachelor students, 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 (AT) group coordinates and promotes actions dedicated to university students at the several levels (undergraduate, master, doctoral), providing high-quality training and ensuring LIP's capability to attract, engage and retain research students. In 2020, the COVID-19 pandemic impacted the Lab's normal activity, having also disrupted several training activities. On the one hand, many of the AT events scheduled since mid-March were held remotely or cancelled. On the other hand, some of the activities also explored new opportunities facilitated by the remote working environment. The LIP Internship Programme, our flagship initiative for undergraduate students, was not noticeably affected: the standard dates that had been defined earlier were kept, and it received the same usual level of enthusiasm, on the part of both supervisors and students, as inferred from the numbers of projects proposed (39) and students subscribed (67), involving all three LIP nodes. The program did nonetheless move to an entirely online format. This circumstance did clearly pose new challenges, which were however addressed by adapting and deploying correspondingly new ideas and tools. Some schools and workshops scheduled for the beginning of the year could also still be held, namely the 5th Lisbon Mini School on Particle and Astroparticle Physics; the 1st LIP GEANT4 introductory course; the LHC Physics Course (mostly online). On the other hand, for several events for which the possibility of social interaction and spontaneous in-person discussions were deemed more critical the decision was to postpone (now tentatively to late 2021). LIP referencing of scientific documentation was fully implemented, spearheaded by the novel LIP student papers. In 2020 FCT and LIP promoted calls within the PhD programmes PT-CERN and ProtoTera. In total, 17 grants have been awarded. For 2021 the strategy is to prepare most events to be held online, as baseline, while remaining ready to move to presential mode whenever that becomes possible. Priorities are the LIP Internship Programme, Data Science school and workshop, Joint IDPASC and LIP student workshop, and IDPASC international school.

Advanced Training

Overview

LIP has a long standing experience in advanced training and permanently hosts tens of doctoral (PhD), master and bachelor 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 was created to coordinate and promote actions dedicated to 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 research at LIP, 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 main goals of LIP's advanced training group for 2020 involved the consolidation and systematic enhancement of existing events and training activities and to support actions towards undergraduate students and graduate students at LIP or part of PhD programmes and networks coordinated by LIP. The Covid-19 pandemic did however impact AT activities: from mid-March on events were either held remotely or in several instances cancelled. It was nonetheless possible to keep the LIP Internship Programme, our flagship initiative for undergraduate students, with the same level of involvement and productivity, despite this year's edition having been held online. Some schools and workshops planned for early in the year could also still be held.

LIP Internship Programme

In 2020, the programme had its fourth edition [1], which was fully held online. A standard high number of students participated in the programme over the summer period, involving about all research groups across the three LIP nodes. The programme kept the same overall structure: a preparatory week (lectures and hands-on tutorials) [2], development of a research project (during up to two months), and a two-day final workshop [3] in which the students presented their work. Lectures were complemented with thematic discussions, organized in small groups of students and researchers, held in separate virtual simultaneous rooms. The programme counted with a broad participation of LIP researchers, who served as project supervisors, delivered tutorials and lectures, guided topical discussions, and attended and contributed to the discussion at the final workshop. 56 students presented their work at the final workshop, successfully completing the program.

The move to an online format did involve challenges that required added flexibility and the exploration of novel approaches. From the program's outreach sessions to student account creation and support. From hands-on training sessions and thematic discussions to introducing students to their respective projects and guiding their development through the course of the internship. A variety of communication and collaboration online tools was employed, starting with Zoom and a centrally provided Slack area, along with Github code repositories, Sharepoint document libraries, Colab and other notebooks and apps. The remote format further facilitated the participation of students and co-supervisors from abroad (CERN, UK, Brazil, US).

Student papers: In addition to the final oral presentations, students are given the opportunity to report their work in the form of a scientific paper. This is 5 to 10 pages long and follows a prepared common template. While this opportunity had been tentatively introduced in the previous edition, the challenge has been fully adopted in this edition as a common deliverable by the majority of the students (2/3 of the projects were documented in this fashion). The reports (30) from both years, 2019 and 2020, have been published as LIP notes. They were processed (latex), referenced (LIP-STUDENTS-yy-xx), uploaded to databases [4], and released in the LIP web site (AT section) [5].

5th edition of the Lisbon mini-school in particle and astroparticle physics: co-organized by LIP and CFTP, it was held in Costa da Caparica in February and gathered 30 undergraduate students from several universities [6]. It included lectures, hands-on exercises, and introductory overviews of ongoing research activity at LIP.

6th IDPASC/LIP PhD students workshop: took place online, with over 70 participants; it included 25 PhD student talks; keynote talks; and 7 master student posters, including short video presentations [7].

LIP GEANT4 introductory course: organized by the LIP Simulation & Big Data Competence Center, it took place in Braga in February. It was attended by 17 participants from high-energy physics, material science and medical physics fields [8]. Further sessions that had been planned for Coimbra and Lisbon later in the year were postponed.

Physics at the LHC course: The course took place online between March and May, in a total of 19 lectures [9]. The typical attendance of each lecture was 5-10 students. Five students gave a final presentation followed by discussion that served as final evaluation. The course is valid for ECTS credits at IST.

LIP Seminars: Regularly held at the three LIP nodes; since 2020, these have been mostly online [10].

Outreach for undergraduates: LIP regularly participates in events organized by physics student associations at the different universities.

Graduate programs: During 2020, LIP hosted over 80 graduate students. LIP coordinates the FCT doctoral programs IDPASC (Particle Physics, Astrophysics and Cosmology) and DAEPHYS (Doctorate in Applied Physics and Physics Engineering), and the IDPASC international network. In the beginning of 2020, FCT and LIP agreed and approved two PhD grant programmes. These are in particle physics and related scientific and technological domains relevant for the Portuguese participation at CERN (PT-CERN), and in proton therapy (ProtoTera) as a follow-up of the creation of the ProtoTera Association. Two PT-CERN calls were opened during the year, in February and September, and in each of them two domains were considered: Particle and Astroparticle Physics and associated scientific domains; Technologies associated to the Portuguese participation at CERN and their transfer to society. Four candidates were selected in the first call, two in each domain. In the September call, eight candidates were selected, six in Physics and two in Technologies. The first ProtoTera call was open in September and five candidates were selected.

Support to FCT's programmes for advanced training in international organizations: LIP supports since its beginning the FCT programme "Advanced training of engineers in the International Organizations - CERN, ESA and ESO", now with a separate call for CERN. A follow-up workshop was organized online on December 17th, 2020, in which 16 trainees presented the progress of their work and future plans. The 2020 call could unfortunately not be launched. This was due to delays in the update of its regulation, required by changes in the law regulating fellowships.

Particle physics for the future of Europe: In the context of the conclusion of the ESPPU process and deliberations in June 2020, two sessions were organised in July and September [11], at IST. The latter workshop aimed at gathering the broader HEP local community to reflect on related opportunities. Naturally, it was and remains here important not only to share status and perspectives but to involve young students in the process (after all, given the medium- and long-term scope of the strategy, its implementation and future upgrades require participation of younger colleagues).

Student and Young Researcher awards 2020: A balloon experiment proposed by SAC students from the University of Coimbra supported by LIP was selected by ESA. A PhD student (A. Carvalho) received an ATLAS PhD Grant. Two young researchers (K. Shchelina, T. Niknejad) have each received recognition awards by the CMS Collaboration.

Activities for which the possibility of more direct social interaction and spontaneous discussions were considered a more fundamental element the decision was taken to postpone — tentatively to late 2021. This was the case of the LIP/IDPASC student workshop, Data Science schools and symposium and IDPAC school in Nazaré. As for scientific communication training of LIP's graduate students, no specific training actions were organized in 2020; it effectively took place through the volunteer participation of several PhD and master students in other AT and ECO activities.

[1] https://www.lip.pt/training/summer-student-program

[2] https://indico.lip.pt/event/716

[3] https://indico.lip.pt/event/717

[4] cern.ch/lip/pub, db.lip.pt

[5] https://www.lip.pt/?section=training&page=student-publications

[6] https://indico.lip.pt/event/633

[7] https://indico.lip.pt/event/699

[8] https://indico.lip.pt/event/681

[9] https://events.idpasc.lip.pt/LIP/events/2020_lhc_physics

[10] https://indico.lip.pt/category/70

[11] https://indico.lip.pt/event/738/, https://indico.lip.pt/event/748

Lines of work and objectives for next year

Planning for 2021 involves also dealing with the uncertainty associated to the evolution of the pandemic situation. The strategy is to prepare most events to be held online, while remaining ready to move to presential mode, towards later in the year or whenever that becomes possible. This should allow us to stay as close as possible to the planning of a standard year.

Some of the key initiatives foreseen for 2021 are:

LIP Internship Programme: to ensure the next edition (5th) of the program is held successfully, retaining the participation of a large number of researchers and students across all three LIP nodes; the baseline planning follows that of the previous edition; it builds on the success attained and experience acquired in the previous years to continue to make improvements and implement further engaging actions.

Undergraduate students: the Data Science School and Workshop, focused on the link to the non-academic sector, is now foreseen to be held in Coimbra in the Autumn. LIP will also continue to participate on a regular basis in events organized by the universities.

Graduate students: among the regular event series, we expect to be able to keep the online version of the LHC physics course and to go back to the presential Joint IDPASC and LIP student workshop and IDPASC international school, tentatively in Nazaré. PhD grant calls are expected to open in the framework of both the PT-CERN and ProtoTera programmes.

Medium-term (3-5 years) prospects

Advanced training shall remain a core aspect of the Lab. From facilitating scientific training to young university students to engaging and supporting graduate students who fuel and advance LIP's research.
Over the last few 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 young 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.

A set of core AT activities shall be maintained and enhanced and novel actions encouraged and supported. Such improvements are based on the acquired experience, and feedback from both researches 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 reveal 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 to collaboration and scientific communication. Furthermore, the associated activities provide the opportunity for younger LIP researchers, including Master 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 [5]. And it shall be extended to include further contributions, such as works developed in the context of university courses coordinated by LIP members; thesis documents; and outreach, didactic and scientific materials produced by LIP researchers.

Activities and accompanying mechanisms for reinforcing the baseline training of LIP graduate students and timely project development, assessment and conclusion shall be considered.

SWOT Analysis

Strengths

The motivation of the team and of the entire LIP community for the need to attract students and to provide excellent training and guidance to those already hosted at LIP; the LIP researchers as highly committed supervisors.

Weaknesses

That 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 classroom environment; absence of direct funding for (core) AT activities.

Opportunities

The success of the activities developed in the few couple of years has already given a greater visibility to LIP among university students and beyond; the recent opening of few positions at universities is starting to strengthen their links with LIP.

Threats

The potential lack of renewed manpower to implement and steer activities; risk that multiplication of activities results in few poorly organized events that damage LIP's achieved reputation.

Advanced Training

Publications

30 LIP Students notes

- R. Machado: *"Characterization of scintillators for the Future Circular Collider as a function of their dimensions", LIP-STUDENTS-19-01*
- L. Oliveira: *"Geant4 simulations on argon transparency to neutrons", LIP-STUDENTS-19-02*
- I. Rebanda, R. Gazola: *"Heavy flavour jets production in Pb+Pb collsions with the ATLAS detector", LIP-STUDENTS-19-03*
- Rita Silva: *"AMBER – physics simulations for a new experiment at CERN", LIP-STUDENTS-19-04*
- F. Albergaria, H. Borges: *"Measurement of J/psi polarization in pp collisions at root(s) = 8 TeV in CMS", LIP-STUDENTS-19-05*
- M. Guerreiro: *"Search for exclusive top quark pair production at the LHC", LIP-STUDENTS-19-06*
- I. Panadero, H. Miranda, F. Laranjinha: *"Plastic in particle physics – aging of WLS Optical fibers using the Fibrometer testbench of LOMaC", LIP-STUDENTS-19-07*
- J. Gonçalves, A. Pardal: *"B mesons as novel probes of QGP", LIP-STUDENTS-19-08*
- Camila Costa: *"Gamma-ray astrophysics with current and future detectors", LIP-STUDENTS-20-01*
- Pedro Costa: *"Development of a next generation detector concept to detect astrophysical gamma rays", LIP-STUDENTS-20-02*
- Ema Mendes, Marcelo Gonçalves: *"Exploring the fast evolution of quark gluon plasma", LIP-STUDENTS-20-03*
- Galetsky Vladlen: *"Machine learning methods to improve boosted Higgs boson tagging at ATLAS", LIP-STUDENTS-20-04*
- Catarina Corte-Real, Francisco Feliciano: *"The hidden charm in the COMPASS experiment at CERN", LIP-STUDENTS-20-05*
- Miguel Peixoto: *"Advanced data analysis methods for dark matter research associated withthe quark top at the LHC", LIP-STUDENTS-20-06*
- Filipe Cunha: *"Study of jet quenching phenomenon using deep neural networks", LIP-STUDENTS-20-07*
- Heitor Österdahl: *"Hadron structure from nonperturbative QCD: the quark propagator DSE", LIP-STUDENTS-20-08*
- Gilberto Cunha: *"Deep neural network uncertainties in VLQ search at LHC", LIP-STUDENTS-20-09*
- Miguel Pereira, Jorge Gouveia: *"A proposal for a graphic analysis of public data from the fluorescence detec-tor of the Pierre Auger Observatory", LIP-STUDENTS-20-10*
- Luís Amorim, Magda Duarte: *"Muography of a building", LIP-STUDENTS-20-11*
- Hilberto Silva: *"Probing the Standard Model with forward proton tagging", LIP-STUDENTS-20-12*
- Mafalda Neves, Nuno Brito, Nuno Campos: *"Search for Higgs boson on the ZZ decay channel", LIP-STUDENTS-20-13*
- Helena Macedo, Inês Sequeira, Tiago Martins: *"Sensitivity of LUX-ZEPLIN to the neutrinoless double beta decay of 136Xe", LIP-STUDENTS-20-14*
- Eduardo Ferreira: *"From light-front wave functions to parton distribution functions", LIP-STUDENTS-20-15*
- Vicente Mendes: *"B-jet interaction with the quark gluon plasma in PbPb collisions with the ATLAS detector", LIP-STUDENTS-20-16*
- Francisco Safara, Raúl Santos: *"Search for dark matter and supersymmetry using machine learning at SHiP", LIP-STUDENTS-20-17*
- Allan Jales, Thomas Gaehtgens: *"Muon efficiency studies using Tag and Probe method", LIP-STUDENTS-20-18*
- Maria Faria: *"Measurement of B meson production in pp collisions at 5 TeV", LIP-STUDENTS-20-19*
- Lia Pereira: *"Optical properties of scintillating materials for high resolution dosimetry using FLUKA and data", LIP-STUDENTS-20-20*
- Joana Mota, Matilde Simões, Francisco Casalinho: *"Observação de muões cósmicos", LIP-STUDENTS-20-21*
- Tomas Sousa: *"Study of background from tritium and 37Ar decays in LZ using Monte Carlo simulations", LIP-STUDENTS-20-22*

SCIENCE AND SOCIETY

ECO

Education, Communication and Outreach

Coordinator(s):
Catarina Espírito Santo, Pedro Abreu

Team:
Ana Sofia Inácio, Carlos Manuel, Conceição Abreu, Filipe Veloso, Henrique Carvalho, Hugo Gomes, Luís Afonso, Matteo Pisano, Nuno Castro, Ricardo Barrué, Ricardo Gonçalo, Sofia Andringa,
Sónia Ribeiro

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. Due to the pandemic, the vast majority of the LIP community was in telework mode during the entire 2020. The priority of internal communications was thus to keep the comunity informed, linked and cohese during the year, through a specific set of dedicated actions and tools. Concerning external institutional communications, the coverage of the EPPSU approval, the LIP-News Bulletin featuring Proton Therapy in Portugal, and the support to the preparation of the application to the Associate Laboratory call were the highlights of the year. An increase in human resources with expertise in design allowed for considerable progress in tasks related to the image and visual identity LIP and the production of promotion material. The education and outreach activities were more severely affected, as from mid-March on all events were either canceled or held remotely. This concerns both the well-established education and outreach programmes, and even more the new lines of activity. Nevertheless, an effort to keep in touch with the school community all along the year was maintained, and towards the end of the year it was possible to organize a few very successful online events. The European Researchers Night, the wide participation in Ciência Viva's "Space goes to school" and the LIP Internship Program are some of the highlights. Planning for 2021 involves dealing with the uncertainty on the pandemic evolution. On the other hand, the revision of LIP's Communication Strategy Document, which should be performed every five years, is due soon. The preparatory discussion must involve the LIP management and community.

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.

LIP's Communication Strategy Document (2016) 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. 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 maximizing 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

In the plan for 2020 we defined as priority the consolidation of the activities and services already provided by LIP-ECO to the LIP community and to the public, given the limited human and material resources available. Particularly important goals were the consolidation of the nation-wide structure of the LIP-ECO group, the efforts to further engage the LIP community in ECO activities, and the reinforcement of the human resources in specific areas, possibly through internships in science communication or design. Regarding our international partnerships, the contribution to IPPOG and EPPCN in the context of the newly approved European Strategy of Particle Physics Update were a clear priority.

The fact that 2020 was a consolidation year rather than an expansion year made it possible, to some extent, to minimize the impact of the pandemic on the ECO activity plan. Obviously, the education and outreach activities were more severely affected, as from mid-March on all events were either cancelled or held remotely.

1. Communications

Externally, the main goal was to promote the visibility and the reputation of LIP, as a way to support the priorities of the laboratory, particularly in what concerns funding and scientific employment. Our peer universities and research centres were considered the priority audience. Following LIP's strategy, communications in 2020 had a double focus:

- fundamental science, where the priority for the year was anticipating the LHC high-luminosity phase and the European Strategy for Particle Physics, but without forgetting the participation in world-leading particle and astroparticle physics experiment and the strengthening of the theory side of the laboratory.
- applications, where the priority for the year was proton therapy in Portugal, but without forgetting LIP's key role in distributed and high performance computing, the growing expertise in data science and the role of LIP in Space.

Concerning internal communications, the original plan was for LIP-ECO to help reinforcing the lab culture at LIP, namely participating in the creation of new discussions forums and meeting opportunities. Due to the pandemic, the vast majority of the overall LIP community was in telework mode during the entire 2020. The priority of internal communications was thus to keep the community bound and informed.

In 2020, LIP hosted three design and communication students in professional internship. One of them is still in the group, with a part-time contract. This increase in human resources allowed for considerable progress in tasks related to the image of LIP and the production of promotion material.

The main communication activities of the year are listed below:

(i) Jornadas LIP (February 2020) | The most important meeting of the LIP community, organized every second year by the Scientific Council Board, was held in Braga early in the year. LIP-ECO was represented by Ana Sofia Inácio (SNO+ PhD student managing LIP's social media) and Luís Afonso (high-school teacher collaborating at EduLab).

(ii) LIP reports (January to March 2020) | Preparation of LIP's detailed and public reports 2019/2020, based on the individual group

reports. Members of the editorial committee: Catarina Espírito Santo, Ricardo Gonçalo, Carlos Manuel (design), Helmut Wolters (database).

(iii) Response to Covid-19 (March to December) | The ECO group focused in two lines of response: contribute to keep the community informed at all stages of the pandemic evolution; make all efforts to keep the LIP community linked and cohese during the year. The main tools and actions were the following: the cLIP digital newsletter was instrumental, particularly during the lockdown periods. It was used to share information, but also to collect information (through surveys, for example on telework ,and other opportunities to share experiences and needs) and to advertise the "virtual meeting points" (in particular the virtual café, held every week along all the year, seminars and debates). The LIP seminars (currently organized by Ruben Conceição and Valetina Lozza in Lisbon, and with the collaboration of Filipe Veloso in Coimbra) were kept online during the full 2020 and naturally became nation-wide.

(iv) EPPSU (June 2020) | The European Strategy for Particle Physics Update was approved by the CERN Council in early June. In the framework of EPPCN, LIP contributed to the ESPPU communications plan and was in charge of the event media communication in Portugal. This was in fact the most mediatic moment of the year for LIP. As home institution of the Portuguese Delegate to the CERN Council (Mário Pimenta), LIP promoted the organization of two sessions on the strategy and its importance for Portugal and Europe: a session devoted to industry (co-organized with CTN/IST in June), and a scientific discussion gathering the Portuguese particle physics community.

(v) Site and online communication channels | The LIP-ECO group managed LIP's presence in the social media (facebook, twitter, linkedin, Youtube, site news and event list), LIP's digital newsletter cLIP and contributed to the maintenance of LIP's site and LIP's scientific database. Actions to help fighting Covid-19 undertaken by LIP members were consistently advertised in the site news, social media and LIP-News Bulletin.

(vi) Branding | A considerable effort has been put into the renovation of LIP's visual identity and preparation of the graphic standards manual. The output of this task, essential for the full development of the LIP brand, will be submitted for approval in 2021. Team: Sónia Ribeiro, Carlos Manuel, Hugo Gomes, Henrique Carvalho, Catarina Espírito Santo.

(vii) Event communication support | Preparation of merchandising items for the LIP Internship Program and of invitations and posters for several (online) events.

(viii) LIP-News Bulletin nb. 17 (June-August 2020) | Publication of issue nb. 17 of the LIP-News Bulletin, closely aligned with the priorities defined above (cover: proton therapy) and containing a special section on the LIP response to the pandemic. Editorial board: Catarina Espírito Santo, Conceição abreu, Ricardo Gonçalo, Sofia Andringa, Carlos Manuel (design).

(ix) Associate Laboratory call (October to December 2020) | Support to the Directorate and Scientific Council Board in the preparation of the scientific documentation for LIP's application to FCT's call for the renewal of the "Associated Laboratory" statute.

(x) Support to LouMu | In the framework of LIP's muon tomography project in Lousal (CV), and in collaboration with the Auger and SWGO groups, the LIP-ECO team designed and produced a flyer and several information boards on different aspects of the project, both for the visitor centre and for the detector location (inside the mine gallery). Team: Sofia Andringa, Sónia Ribeiro.

(xi) The Portuguese representation in EPPCN passed from Pedro Abreu to Catarina Espírito Santo in 2020, and the EPPCN agreement was renewed for another five years.

2. Education and outreach

Education and outreach activities in 2020 were severely affect by the pandemic. This concerns both the well-established education and outreach programmes, which in several cases had to be postponed, and even more the new lines of activity. Nevertheless, an effort to keep in touch with the school community all along the year was maintained, and towards the end of the year it was possible to organize a few very successful online events.

(i) IPPOG's International Masterclasses in Particle Physics were foreseen to take place in around a dozen places all over the country, under the coordination of LIP. However, only the first few sessions (namely in Braga, Bragança and Vila Real) took place before March 11th, for a total of about 400 participants, when the first lockdown started in Portugal. Schools were functioning remotely until the end of the 2019/2020 school year.

(ii) CERN's Teachers Programme in Portuguese Language had to be postponed to 2021.

(iii) The BL4S (Beamline for Schools) competition, launched by CERN in 2014, invites secondary school students to submit a proposal for an experiment to be performed at a beam line, in the form of a report and a short video. LIP is the scientific

support partner for the portuguese speaking countries (except Brazil since 2017). In 2020, for which the two winning teams will carry out their experiments at DESY, a total of 207 teams from 47 countries have submitted a proposal, out of which 23 teams from 17 countries were shortlisted. A total of 5 portuguese teams applied and, for the third time in this competition, a portuguese team was selected to the shortlist.

(iv) Clubes Ciência Viva stem from a joint initiative of the Ministry of Education and of the Ministry of Science, Technology and Higher Education (via Ciência Viva Agency). A total of 237 clubs were approved so far and LIP is the scientific partner in 6 of them. Within the activities of these clubs, LIP goes to the school to meet the students, give seminars and support the students participating in BL4S, "World Wide Data Day" or the "Masterclasses".

(v) Scientifically Probable is a programme from the network of school libraries from the Ministry of Education, of which LIP is a partner since its launch in 2017. In the beginning of 2020, we gave a public lecture at the Beja Municipality Library, which was full of people of all ages learning about the Higgs field and our Universe.

(vi) The Science in the Summer CV internship programme for high-school students took place remotely at LIP, welcoming 10 participants in 4 LIP groups under LIP-ECO's organization. The main advantage of online internships was that students from all over the country could participate. The possibility of keeping a remote component next year will be considered.

(vii) LIP maintained its participation on the CV "Space goes to school" event, with over 17 talks in schools (most of them in remote mode) and the participation of researchers from several LIP groups. In this case, the combination of regular visits to schools with the use of remote communication technologies is a clear advantage for the programme and should be kept in the future, as it allowed for a much wider geographical reach. LIP also visited schools in many other occasions, totalising over 50 outreach talks in presence or online by several LIP researchers.

(viii) The European Researcher's night was postponed from end of September to end of November. It was finally held on zoom with life streaming (and questions) on Youtube during the National Week of Scientific and Technological Culture, and it was an example of very good collaboration between the three LIP nodes: the programme started with a virtual visit to the ATLAS experiment organized by the Braga team, it went on with an online discussion/debate with a panel of LIP students and young researchers (from the three nodes) about opportunities and career paths in physics, organized by the Coimbra node, and finished in (remote) Lisbon with a virtual visit to CMS followed by a long Q&A session. A few hundred (275) people attended at least part of the session, in an evening in which many online sessions about science were happening in Portugal.

(ix) The development of the LIP-EduLab was considerably affected by the pandemic and by the restriction on *in situ* activities at LIP. While some individual work was kept and had important developments (in projects such as the cloud chamber assembly kits, MIT's CosmicWatch detectors and the model of the ATLAS magnetic system), the project as a whole was basically on halt, as collaborative work was problematic and not an urgent need.

(x) World Wide Data Day. This is an IPPOG activity proposed by one of its members (quarknet from USA, https://quarknet.org /content/world-wide-data-day), to have school students analyse real data from ATLAS or CMS and discuss their results through video-conference. It is meant to offer 30 minutes video-conferences running for 24 hours with different schools. LIP supports this programme, by promoting it to our partner schools, helping the students and having LIP researchers as moderators of some video-conferences. In 12 november 2020, 55 schools participated in this activity, out of which 4 from Portugal. A LIP researcher was moderator in 4 out of the 15 video-conferences held.

(xi) LIP's involvement in IPPOG become much stronger, following the election of a LIP Researcher as IPPOG Co-Chair (Pedro Abreu, mandate 2020-2022). Ricardo Gonçalo was then nominated as IPPOG portuguese representative. IPPOG held two virtual meetings in 2020, the Spring meeting focussing on formal education (for example, the use of Masterclass-like activities in the school curricula) and the Autumn meeting focussing on the next steps following ESPPU and the implementation of its recommendations, involving also other groups such as EPPCN.

Lines of work and objectives for next year

Planning for 2021 involves dealing with the uncertainty on the pandemic evolution. The strategy is to prepare most public events and outreach activities to be held online, while being ready to move to presential mode whenever this becomes possible. Key goals for 2021 are listed below:

1. Communications

Editorial

- Achieve a regular, monthly publication of the internal digital newsletter cLIP
- Publish the LIP-News Bulletin as soon as it can be physically distributed
- Strengthen LIP's presence online, in particular by reinforcing its social media

Branding and communication material

- Complete and apply the work on the renovation of the visual identity of LIP
- Make progress on the preparation of new communication materials such as flyers and short movies
- Regularly present our work to the LIP community, namely in LIP seminars
- Resume and broaden the SciCom training sessions for the LIP community

Open lab days/public sessions - organize public session (remote if required) in the following occasions:

- International day of Women and Girls in Science;
- LIP's 35th anniversary;
- European Researcher's Night;
- National Week for the Promotion of the Scientific and Technological Culture.

Seek to reinforce the available human resources

- Keep the close collaboration with the Computing group and the Administrative services at LIP;
- Promote a wider participation of the LIP groups in ECO (namely recently arriving groups);
- With the management, examine the possibilities of consolidating the dedicated resources;

SciCom research

It is our goal to seek to define a science communication research project based on LIP's ECO experience (activity development and evaluation efforts). The project should include all LIP nodes, as well as external SciCom partners. The goals would be in a first phase, to consolidate internally our activities and projects, and to enlarge our network in the area. And in a second phase to be able to attract funding and to publish our results.

2. Education and outreach

Masterclasses

- All sessions will be held online via Zoom.
- LIP will promote sessions on saturdays only, covering all the saturdays within the dates of the international programme (mid-February to end of March), and will try to engage the previous partner universities and institutions in co-organizing these online sessions.

Schools activities

- The Beamline for Schools competition (BL4S) is promoted by CERN and DESY, and will allow for two winning teams to run their proposed experiments in a beamline at DESY. LIP provides scientific support to the competing portuguese teams (and teams from schools in portuguese speaking countries, except Brazil), in the preparation of their proposals.
- LIP is scientific partner to six Clubes Ciência Viva, providing activities and outreach talks. Hopefully, and pandemic conditions allowing, these will increase the presence of LIP at the involved schools.
- LIP will continue and increase its presence in libraries and other informal spaces through Cientificamente Provável and similar programs, talking to publics of all ages about our [mis]understanding of our universe.
- Within the "Space goes to school" programme from the ESERO-Portugal project of Ciência Viva Agency, LIP plans to do outreach talks at schools requesting our presence, consolidating the increasing number of requests since the start of this programme.
- Outreach talks at schools. Within the previous three items or independently of them, LIP is planning to continue to develop its strong presence at schools via outreach seminars, along the year, in presence or virtually.

FICA2021

- The municipality of Oeiras is organizing a science festival, one week long, scheduled for October 6th-12th, subject to pandemic conditions allowing it to happen. LIP is proposing to support the installation and use of the CERN's engaging

LHC Interactive Tunnel (featured in the exhibition "Particles: from the Higgs to dark matter" in 2016), along a few other items (LIP's spark chamber, LIP's cloud chamber, posters and flyers, workshops and outreach seminars).

Medium-term (3-5 years) prospects

The revision of LIP's Communication Strategy Document, which should be performed every five years, is due soon. This is the right moment to review our medium-term strategy. In the first five years the priorities concerned internal communications (contribute to strengthen a lab culture and to raise awareness on the importance of communicating and promoting LIP). While this effort must be continued, we have now to enhance our communication towards the outside world: it is crucial for the future of LIP to create a solid reputation for the institution, whithin the scientific and academic system at large and beyond that. This will require a careful articulation with the management, and with LIP's strategy for the next five years.

From the point of view of the group itself, an ambitious goal is to become not only a service provider in the laboratory, but also a research group with recognized work in its domain: science communication and education. Obviously, this step can only be taken once the role as a service provider is firmly established.

The lack of resources, mostly human but also material, clearly limits not only the possibilities of expansion of LIP's ECO activities but also its efficiency. The needs for what concerns human resources are clearly identified:

- Additional resources on design now available.
- A science communicator to help with the routine work of institutional communication (site news, social media, etc.), leaving some time for other projects.
- A lab technician (or partial contribution of someone with another job at LIP), to give support to the development and installation of the EduLab in Lisbon.
- A person for education and outreach content development, who could integrate and boost the work developed by several LIP researchers in very small fractions of their time.

Funding for education and outreach activities has been very scarce in the last few years, and several of the mechanisms implemented nearly 20 years ago are no longer in place. It is thus an urgent need for LIP-ECO to find new ways to attract funding, either via relevant science communication research work or via new opportunities related to some the country's strategic priorities (such as fighting exclusion, improving the qualification of the population, facilitating the digital transition, ...). We need funding mostly for human resources, equipment, content and material development.

Additional pieces in our strategy are to strengthen to link between LIP nodes (all projects should be national), widen the training and the participation of LIP researchers. Widen the publics and the type of events proposed (not only high-school, not only talks). Younger public and also adults.

SWOT Analysis

Strengths: The strong motivation of the team and the wide range of expertise covered — from particle physics to science communication, from computing to graphical design. The support from the LIP management and recognition of the work developed in the last few years, which considerably increased awareness on the importance of ECO activities at LIP. Our network of nearly 1400 high-school teachers is a valuable asset to engage schools in our activities, taking advantage also of their distribution over the country. Our integration in international networks for ECO.

Weaknesses: The lack of dedicated human and material resources. Most team members are highly committed to other tasks and devote only a small fraction of their time to ECO. After dealing with everyday tasks, there is little time left to expand our activities or to implement new ideas.

Opportunities: The support of the LIP management and of a good fraction of the LIP community. The will to participate shown by several graduate students and young researchers. The many suggestions received from LIP members. The recent reinforcement of the human resources with design expertise. The fact that ECO activities are increasingly considered as an essential part of the work of research institutions.

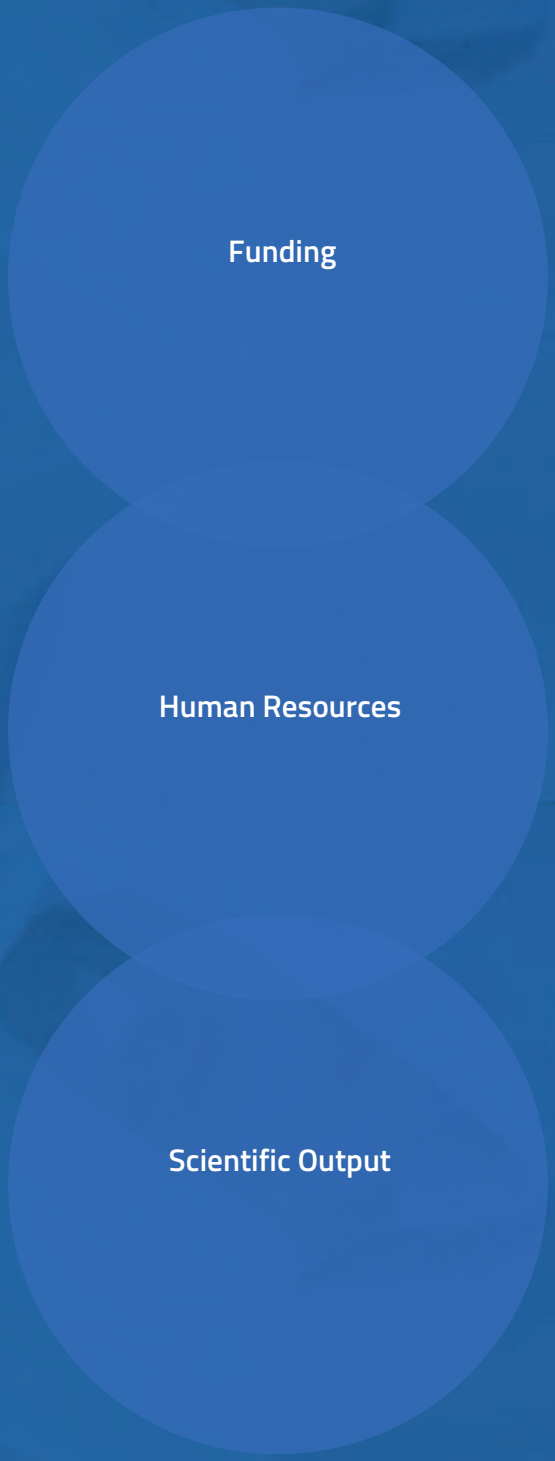
Threats: We still need to build a more solid and wider reputation for LIP within the national scientific system at large. The lack of increase of material or human resources. The fact that many people in the community still believe ECO activities are a minor issue and should only consume minimal resources. The currently prevalent tendency in Portugal, both among general public and policy makers, to value only applied science, particularly in the area of health.

Sources of funding

PI	Code	Amount	Dates	Description
Pedro Abreu	EPPCN - KE2826	23.500 €	2016-01-01 / 2020-12-31	EPPCN Agreement

Total: 23.500 €

Summary Tables



FUNDING

Group	Code	Amount	Dates	LIP node
ATLAS	CERN/FIS-PAR/0033/2019	191.250 €	2019-09-01 / 2021-08-31	L, C, M
"	CERN/FIS-PAR/0002/2019	180.000 €	2019-09-01 / 2021-08-31	"
"	Fundação La Caixa - Inês Ochoa	115.500 €	2020-07-01 / 2023-06-30	"
CMS	aAmuse - Project 101006726	115.000 €	1000-01-01 / 9999-12-31	L
"	CERN/FIS-INS/0032/2019	200.000 €	2019-08-01 / 2021-07-31	"
"	CERN/FIS-PAR/0025/2019	200.000 €	2019-08-01 / 2021-07-31	"
Pheno	CERN/FIS-PAR/0015/2017	10.000 €	2017-11-01 / 2020-08-31	L, C, M
"	CERN/FIS-PAR/0022/2017	30.000 €	2018-03-01 / 2020-02-29	"
"	824093 - STRONG-2020	188.500 €	2019-06-01 / 2023-05-31	"
"	835105 - YoctoLHC	399.062 €	2019-10-01 / 2024-09-30	"
"	CERN/FIS-PAR/0029/2019	45.000 €	2019-11-15 / 2021-11-14	"
"	CERN/FIS-PAR/0024/2019	90.000 €	2020-07-01 / 2022-06-30	"
"	CERN/FIS-PAR/0010/2019	20.000 €	2020-09-01 / 2022-08-31	"
Partons and QCD	CERN/FIS-PAR/0022/2019	155.000 €	2019-09-01 / 2021-08-31	L
NUC-RIA	CERN/FIS-PAR/0005/2017	24.640 €	2018-07-01 / 2020-12-31	L
NPStrong	RD0713	22.382 €	2017-04-01 / 2021-12-31	L
AMS	CERN/FIS-PAR/0013/2019	50.000 €	2019-09-01 / 2021-08-31	L
Auger	CERN/FIS-PAR/0034/2019	135.000 €	2019-09-01 / 2021-08-31	L, C, M
"	CERN/FIS-PAR/0031/2019	75.000 €	2019-09-01 / 2021-08-31	"
LATTES	PTDC/FIS-PAR/29158/2017	239.885 €	2018-05-15 / 2021-05-14	L, C
"	PTDC/FIS-PAR/4300/2020	249.585 €	2021-05-15 / 2024-05-14	"
Dark Matter	IF/00877/2015/CP1311 /CT0002	50.000 €	2016-11-01 / 2021-11-30	L
"	PTDC/FIS-PAR/28567/2017	239.807 €	2018-09-01 / 2021-08-31	"
Neutrino	IF/00248/2015/CP1311 /CT0001	50.000 €	2017-01-01 / 2021-12-31	L

FUNDING

Group	Code	Amount	Dates	LIP node
RPC R&D	STRATOS R&D	20.000 €	2019-01-01 / 2020-12-31	C
"	STRATOS	80.000 €	2019-01-01 / 2020-12-31	"
"	POCI-01-0247-FEDER-039808	120.000 €	2019-06-17 / 2021-10-16	"
"	CERN-FIS-INS-0009-2019	70.000 €	2020-07-01 / 2022-06-30	"
Neutron Detectors	CERN-FIS-INS-0009-2019	70.000 €	2020-01-01 / 2021-12-31	C
Gaseous Detectors R&D	CERN/FIS-INS/0025/2017 (Gaseous Detectors R&D)	70.000 €	2018-05-01 / 2020-04-30	C
"	CERN/FIS-INS/0026/2019 (Gaseous Detectors R&D)	35.000 €	2020-11-01 / 2022-10-31	"
Liquid Xenon R&D	CERN/FIS-INS/0025/2017 (Liquid Xenon R&D)	70.000 €	2018-05-01 / 2020-04-30	C
"	CERN/FIS-INS/0026/2019 (Liquid Xenon R&D)	35.000 €	2020-11-01 / 2022-10-31	"
OR Imaging	CERN/FIS-TEC/0019/2019	90.000 €	2020-01-01 / 2021-12-31	C
"	LISBOA-01-0247-FEDER-045904	200.442 €	2020-01-01 / 2022-12-31	"
Space Rad	ESA: 1-7560/13/NL/HB	300.000 €	2014-02-18 / 2020-12-31	L
i-Astro	654215 - AHEAD	61.225 €	2015-09-02 / 2024-03-01	C
GRID	INCD 01/SAICT/2016 - nº 022153	223.000 €	2017-07-18 / 2021-07-17	L
"	DEEP-HybridDataCloud - Grant 777435	362.500 €	2017-11-01 / 2020-04-30	"
"	EOSC-hub grant 777536	338.687 €	2018-01-01 / 2021-03-31	"
"	EOSC-synergy grant 857647	433.000 €	2019-09-01 / 2022-02-28	"
"	BigHPC 04/SI/2019	249.592 €	2020-03-01 / 2023-02-28	"
"	EUROCC	296.000 €	2020-09-01 / 2022-08-31	"
"	EGI-ACE	196.238 €	2021-02-01 / 2023-08-31	"

Group	Code	Amount	Dates	LIP node
GRID	EOSC-Future	219.000 €	2022-01-01 / 2024-12-31	L
SPAC	FARE - Fake News and Real People (ERC)	1.499.844 €	2020-10-01 / 2025-09-30	L
Simulation & Big Data	PTDC/FIS-PAR/28567/2017	239.990 €	2018-07-01 / 2021-06-30	L, C, M
ECO	EPPCN - KE2826	23.500 €	2016-01-01 / 2020-12-31	L, C, M
TOTAL		**6,878.785 €**		

Human Resources on research

Group	FTE	Persons(*)	Researchers	Technicians	PhD	Master	Undergrad	External
ATLAS	22.1	33	15	5	7	6		17
CMS	13.9	18	12	2	3	1		9
Pheno	14.9	25	17	1	4	3	1	18
Partons and QCD	4.3	6	5	1			1	2
HADES	0.4	4	2	2				
NUC-RIA	6.1	9	5		1	3		3
NPStrong	4	7	4			3	1	
AMS	3.3	5	4		1			3
Auger	12.3	23	15	4	2	2	1	2
SWGO/LATTES	4.6	20	11	4	2	1		6
Dark Matter	13.6	19	9	2	2	6		
Neutrino	6.6	11	8		3			
SHiP	2.5	8	5	2		1	2	
RPC R&D	4	16	8	7	1			
Neutron Detectors	1.2	4	4					1
Gaseous Detectors R&D	5.4	11	8		1	2		
Liquid Xenon R&D	0.6	6	5		1			
OR Imaging	2	3	3					
Dosimetry	6.1	12	4		3	5		

(*) Please note that the total of the Persons column is not the sum of the column, as one person often participates in several groups.

Human Resources on research

Group	FTE	Persons(*)	Researchers	Technicians	PhD	Master	Undergrad	External
Space Rad	3.4	8	7			1		1
i-Astro	5.4	14	10		1	3	1	
GRID	11	12	4	8				6
Advanced Computing	2.8	3	1			2		3
SPAC	2.4	11	5	2	1	3		2
Radiation, health and environment	4.6	8	5		3			1
TOTAL	**157.5**	**296**	**111**	**32**	**33**	**41**	**7**	**74**

Scientific output

Group	Papers w/ Direct Contribution	Papers in Refereed journals	Books, Reports and Proposals	Notes	Oral Presentations Int. Conf.	Poster Presentations Int. Conf.	Other Presentations	Proceedings	PhD	Master	Events
ATLAS	10	81		14	3	4	54	6		4	
CMS	12	104	1	17	5		45	8	2		
Pheno	15	15		1	12		15	4		2	
Partons and QCD	2	6		1	6		5				3
HADES		5					1				
NUC-RIA	5	7								1	
NPStrong	12	12			1		4			1	1
AMS		2			1						
Auger	4	14		3	1		9		1		1
SWGO/LATTES	2	2		2			5				1
Dark Matter	5	11	1	12		1	14		1	2	
Neutrino	6	11			1		4	1			
SHiP	1	6	2	1	1					1	
RPC R&D	3	3			3		1				
Neutron Detectors	2	2			1		1				
Gaseous Detectors R&D		3								2	
Liquid Xenon R&D					2						
OR Imaging							4				
Dosimetry	1	2					3			1	

Scientific output

Group	Papers w/ Direct Contribution	Papers in Refereed journals	Books, Reports and Proposals	Notes	Oral Presentations Int. Conf.	Poster Presentations Int. Conf.	Other Presentations	Proceedings	PhD	Master	Events
Space Rad	2	3		3	3		19	1			
i-Astro							12	1	1	1	1
GRID	3	3		12	6		9	3			1
Advanced Computing											
SPAC	1	1	2		5	1	12				
Radiation, health and environment	4	5									
CCMC				1							
Simulation & Big Data	3	3					15		2	1	2
TOTAL	**85**	**291**	**6**	**79**	**48**	**10**	**216**	**24**	**6**	**15**	**10**

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA
EXPERIMENTAL DE PARTÍCULAS