LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

LIP Detailed Report 2019 and plan for 2020

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Mário Pimenta
President

2019 was for LIP a year of extreme contrasts. In the same month, June, Gaspar Barreira, founder of LIP, passed away, and LIP was considered "Excellent" in the evaluation of all the Portuguese Research Units.

Gaspar worked as few in the construction of a Portugal where Knowledge, Freedom and Rationality were decisive, before and after the Revolution of April 25th 1974. If today we have LIP, which is not just a group of physicists participating in experiments at CERN, but rather a diverse but coherent community of physicists, engineers, technicians, administrative staff and students engaged in the challenges of particle physics, but also of instrumentation, computing and technology, deeply embedded in international and national collaborations, we owe much of it to Gaspar.

The FCT Evaluation Panel recognized the contribution of LIP "to many world-leading experiments at CERN and elsewhere" and its "overall coordinating role of all particle physics in Portugal" which "is essential to be able to have critical mass and to increase the visibility of Portuguese particle physics in large international collaborations". It was also stated that "applications of particle physics to society, such as medical, imaging, dosimetry and other areas of science, such as space, are also very strong, and LIP should be commended for this strategy" and that "the outreach and public understanding of science engagement programme by LIP is also excellent".

LIP is essentially its researchers, engineers, technicians and administrative staff. However, the employment conditions in the medium and long term at LIP are not yet satisfactory. For researchers, the number of permanent positions at LIP and/or at the universities are not at all sufficient. For the other staff members, the career path is not well defined, and the well-deserved career progression was basically inexistent in the last 10 years.

The way forward clearly includes establishing a five-year contract program with FCT on the framework of the running call for "Associate Laboratories", but also to substantially increase LIP's capability to diversify its funding sources. In the next five years, the number of permanent researcher positions at LIP should double (from 12 to 24) and the budget for technical and administrative staff should increase by 50%. In 2019 the total LIP budget for human resources, apart from positions paid by FCT through LIP (FCT researchers or older "long-term" post-Doc grants), was 2.3 M€. This budget should increase in 2025 to 3.7 M€, which means that the total LIP project-based funding also has to double (from about 1.5 M€ to 3 M€). This path has already started in early 2020, with the recovery of the "Fundo CERN" budget nearly to "pretroika" values, with the increase of European funded projects, with new funding for the field of medical physics. Each LIP member and in particular its senior researchers should be well aware of this demanding challenge. New groups have recently joined LIP. In December 2019, the IST Theoretical Nuclear Physics group joined and became the NPStrong (Nuclear Physics and Strong hadronic interactions) LIP Group.

LIP has now the largest Nuclear Physics group in Portugal and thus must be a reference also in this scientific area. The synergies with many other LIP groups are evident: from phenomenology to the neutrinos and dark matter experiments; from medical physics to space applications. Already this year, in February 2020, the Social Physics and Complexity Group (SPAC) joined LIP. It is a small but very active group with strong synergies with the Computing Group and the Competence Centre in Simulation and Big Data. Interactions with other LIP groups, as for instance the Phenomenology Group, may reveal very fruitful. This group enlarges and enriches LIP's scientific and societal intervention areas.

In 2019 FCT signed the High Luminosity LHC (HL-LHC) Memorandum of Understanding (MoU), the activity in DUNE clearly ramped up, and the SWGO collaboration was established.
The signature of the HL-LHC MoUs establishes the participation of Portugal in the upgrade programs of the ATLAS and CMS experiments, which will allow them to operate at five times the nominal LHC luminosity, extending its physics potential very significantly. They are very demanding five-year programs, where the LIP groups, but also the Portuguese Industry, will be fully engaged.

The Deep Underground Neutrino Experiment (DUNE) will consist of a set of detectors observing the Long Baseline Neutrino Facility (LBNF) beam, and supported by a joint venture of Fermilab and CERN, aiming at high precision study of neutrino oscillations, which will allow to explore CP violation and mass hierarchy in the neutrino sector. The two groups at LIP with large experience in underground experiments (SNO+ and LUX/LZ) are now working together in this challenging project.

SWGO, the Southern Wide-field Gamma-ray Observatory, was formed as a result of a workshop meeting in Lisbon, in May 2019. It already counts 44 research institutions from 11 countries and has a well-defined three-year R&D program, to be completed by the end of 2022, and to be followed by the construction phase. By the end of this decade, the Observatory should be fully operational ensuring a permanent coverage of the high-energy gamma-ray Southern sky, in the energy range from 100 GeV to hundreds of TeV. LIP is one of the founding members of the Collaboration.

A new entity, "The Portuguese Proton-Therapy and Advanced Technologies for Cancer Prevention and Treatment Association (ProtoTera)" was created last December. The founding members of ProtoTera are the Portuguese Oncology Institute Hospital Group (IPO), Instituto Superior Técnico (IST), the University of Coimbra (UC), and LIP. The main research centres at the IST and UC are, respectively, CTN (Nuclear technology Centre) and ICNAS (Institute of Nuclear Sciences Applied to Health), with whom LIP has developed a strategic partnership in the last few years.

The vision is to promote a national network for the diagnosis and treatment, research and education on cancer, using high-energy particle beam therapies (namely

proton-therapy), theranostics, dosimetry and advanced medical imaging for the enhancement of precision and personalized medicine. In a first phase, two protonbeam facilities will be installed: one in the CTN campus, with a proton beam of 230 MeV; and another at ICNAS, with a proton beam of 70 MeV. The Lisbon installation will have two/three treatment rooms and one dedicated research room. The Coimbra installation will be specialized in eye cancer treatments and in the production of heavy radioisotopes. Close collaborations with international reference centres will be established, namely with CERN, GSI, the Heidelberg University Hospital, the MD Anderson Cancer and the Trento Proton Therapy Centre.

LIP is a world leader in the development of Resistive Plate Chamber (RPC) particle detectors. However, the funding and the human resources were often below existing needs and justified ambitions.
In the last two years human resources were slightly reinforced, and new funding was obtained. The main projects are presently at different stages, namely:

- The high-resolution RPC-PET brain scanner project, approved last year in a partnership with ICNAS, is developing according to schedule and the full prototype should be operational in 2021;
- The construction of low-flux, autonomous RPCs cameras has attained the production phase, with more than 100 units produced and tested. The first sealed prototypes were built with very encouraging results;
- The RPC-based neutron detectors project is in a critical phase. Interesting results were obtained with small prototypes, but its full technical and commercial feasibility have still to be demonstrated, hopefully within a one-year time scale.
- The reinforcement of the human resources in the group, namely with the inclusion of PhD students, will be determinant to maintain, at medium and long-term, its performance and the ability to lead new large projects.

The computing group is a key piece of LIP. It supports all the LIP IT services, co-manages and ensures the technical operation of the Portuguese National Distributed Computing Infrastructure (INCD), and is deeply involved in Iberian and European international service and research projects. The foreseen needs in computing and data storage of the HL-LHC are enormous (50-100 times greater than today) and there is not yet a clear solution to this problem. LIP will discuss with CERN possible working strategies.

The collaboration (direct and/or through INCD) with the Minho Advanced Computing Centre (MACC) is already effective and will be reinforced in the framework of the installation at Minho of the “Deucalion” supercomputer, which will be a node of the EuroHPC Joint Undertaking.

LIP Scientific Infrastructures are essential for LIP's activity. Re-equipment funds for the Detectors Laboratory (DL) in Coimbra and for the Cosmic Ray Electronic Laboratory (e-CRLab) and the Laboratory of Optics and Scintillating Materials (LOMaC) were assigned as a result of the evaluation of the Portuguese research units. In the DL, the main investment will be in the installation, in the coming months, of a ISO6 clean room. Together with the recent acquisition of a new CNC machine, this will strongly enhance the gaseous detectors building capabilities, including possible opportunities of high-valued external commissions. The investment in the e-CRLab will allow to work in the GHz range
(ns), improve the capability to work outdoors and create new working positions at LIP. By a collaboration with the LIP ATLAS group, the e-CRLab will be responsible for some of the tasks foreseen in the Portuguese participation in the ATLAS detector upgrade program. In this framework, a new technician will be hired and new opportunities for students will exist.
Students are essential for maintaining the vitality of any research institution, and LIP is no exception. Since long, particular attention is given to the promotion of advanced training opportunities for students, that are both top level and broad in field, namely in the framework of IDPASC (Particles Astrophysics and Cosmology) network. The recently created LIP Student Council will for sure contribute to boost the participation of students in the organization of new activities, contributing to further improve the quality of PhD and master students hosting and training at LIP.

The IDPASC-Portugal PhD program had its last call in 2019. A new PhD grant program in particle and astroparticle physics and related scientific and technological domains was agreed between FCT and LIP. The program will have, every year, two calls with a total number of 15 grants. The first call, with two domains (Physics and Technologies), is now open.

LIP’S intense activity in education, outreach and advanced training is no novelty, but it is always a huge and non-trivial effort. Every year, the International Masterclasses in Particle Physics involve more than one thousand high school students all over Portugal, CERN’s Portuguese Language Teachers Programme, co-organized by CERN and LIP, engages tens of high school teachers from Portugal and from Brazil, and the LIP Internships Programme introduces over 50 first-cycle university students to research activities over the Summer.

The 2020 update of the European Strategy for Particle Physics will propose a vision for our medium- and long-term future, exploring both the high-precision and high-energy frontiers. It would always represent a great scientific and technological challenge, and a responsibility for everyone and every institution in high energy physics. But, in the present sanitary and economic crisis, it should also be a key element in Europe´s future: helping Europe to lead Science and Technology and avoiding the brain drain of its best scientists and engineers. LIP will be fully engaged in this endeavour.

(Mário Pimenta)
Lisbon, March 2020

Report from FCT Evaluation

June 2019

Panel: EXACT SCIENCES - Physics

Peter Butler (Chair, University of Liverpool, UK), Deborah O'Connell (University of York, UK), Farvah Nazila Mahmoudi (CERN, Switzerland), Giampaolo Pisano (University of Cardiff, UK), Hanns-Ulrich Habermeier (Max Plank Institute for Solid State Research, Germany), Konstantinos Kokkotas (University of Tübingen, Germany), Paul Soler (University of Glasgow, UK), Rolf Allenspach (IBM Research Division, Zurich Research Laboratory, Switzerland), Tulkki Jukka (Aalto University, Finland), Zaher Salman (Paul Scherrer Institut, Switzerland)

Overall Quality Grade: EXCELLENT

Evaluation Criteria Ratings

(A) Quality, merit, relevance and internationalization of the R&D activities of the Integrated Researchers in the R&D Unit Application: 5

(B) Merit of the team of Integrated Researchers: 4

(C) Appropriateness of objectives, strategy, plan of activities and organization: 5

Justification, Comments and Recommendations

The LIP is the leading Particle Physics R&D Unit in Portugal and contributes to many world-leading experiments at CERN and elsewhere. It consists of 85 Integrated Researchers with a PhD and 76 researchers without a PhD, of which 33 are students studying for their PhD (numbers from 2017, when the Unit application was written). The LIP has built important detector components for major experiments and has led important particle and nuclear physics analyses. The highlights of the group are their important contributions to both the ATLAS and CMS experiments at the Large Hadron Collider (LHC) at CERN, the ultra-high-energy cosmic ray experiment AUGER, dark matter searches at LUX and preparations for LZ, and neutrino physics, particularly in SNO and SNO+. Furthermore, their detector development team not only supplies instrumentation for leading particle physics experiments, but it also has significant impact in other areas of crucial importance to society, such as medical and health science applications.

These are some detailed highlights:

1) Building components of the Tile Calorimeter (TileCal) at ATLAS and its upgrade resulted in an ATLAS outstanding achievement award due to the quality and significance of the work for the collaboration. The Higgs analyses are the main areas of strength, including contributing to the discovery of Higgs decays to two vector bosons (H->WW) and the coupling to third generation quarks (Higgs decays to two beauty quarks H->bb, and associated Higgs production with a top-antitop pair ttH). They collaborate with theorists from CFTC on the ttH discovery channel.

2) The CMS group, while small in size, is really outstanding and world-class. A member of LIP was deputy spokesperson of the CMS collaboration at the time of the Higgs discovery, and has supplied physics working group co-conveners of the CMS Higgs Physics analysis, the Top Quark Physics analysis and the CMS B and Quarkonium Physics group. This is a remarkable achievement for such a small group, to be leading three of the most important physics analysis groups. Highlights include the flagship discovery channel of the Higgs decaying to two photons, which dominates the Higgs mass measurement, top decays to dileptons and the first observation of the Bs->mumu decay, which places severe constraints on Supersymmetry. Forward physics with CTTPS is another area of strength. They also work on the MIP timing detector for the upgrade, to reduce pileup in the High Luminosity LHC, and the CTPPS forward detector.

3) The phenomenology group is also of a very good quality, with top physics and heavy ions the areas of strength. There is collaboration with the experimental groups to define new variables in top-quark physics and development of new state-of-the-art Monte Carlo generators. The existence of a phenomenology group in a laboratory predominantly dedicated to experimental particle physics and instrumentation is very positive and should be encouraged.

4) The Partons and QCD (PQCD) group is small in size and is focussed on the COMPASS experiment at CERN, where they contributed to the monitoring and control system. The main physics highlights include measurements of polarisation in Drell-Yan processes and a future programme of deep-inelastic scattering at COMPASS.

5) The Low Energy Interactions (LEHRI) group is also small and focussed on work at GSI and FAIR in Germany. They have contributed to the construction of major pieces of hardware, such as the Restive Plate Chamber (RPC) wall for HADES and the CALIFA calorimeter for R3B. Dilepton production from Au+Au collisions in HADES is the physics highlight.

6) The cosmic ray group works on extremely high energy cosmic rays at the largest air-shower array in the world (AUGER) in Argentina and the AMS experiment at the international space station. For AUGER the group is supplying RPC modules to enhance the detection of muons in air showers and has confirmed a long-standing problem of a muon deficit in ultra-high-energy showers. For AMS, the group supplied the Ring Imaging Cherenkov (RICH) detector for particle identification and studies solar modulations of cosmic rays.

7) The neutrino physics group is involved in the Sudbury Neutrino Observatory (SNO, SNO+), in NEXT and DUNE. The group has an important responsibility for the calibration insertion system for SNO+, whose aim is to measure neutrino-less double beta decay in a high-mass tellurium sample. The NEXT experiment is also a double-beta decay experiment at the Canfranc laboratory, but using high-pressure gaseous xenon Time Projection Chamber (TPC) in the Spanish Pyrenees. The two experiments are complementary, since one is a high-mass experiment and the other is a high-precision experiment. These are both very important for the future of the field to determine whether neutrinos are their own antiparticle (Majorana particles) or not. The effort of LIP in the long-baseline neutrino experiment DUNE in the USA is still under negotiation, but it involves calibration systems and the protoDUNE prototype at CERN.

8) Dark matter is another of the area of strength with participation in ZEPLIN, LUX, LZ and future dark matter searches using liquid xenon with international collaboration. They have had leading roles (data analysis coordinator and reconstruction coordinator) for the LUX experiment that has set world-leading limits on Weakly Interacting Massive Particle (WIMP) dark matter candidates. The group also provides the manager of the LZ control system, which will be the foremost dark matter experiment, currently under construction.

9) The detector development group has world-leading expertise in resistive plate chambers, with exceptional timing and position resolution, and noble gas Time Projection Chamber technology (both liquid and gaseous xenon).

10) The health and biomedical applications group is an excellent example of impact of particle physics research and detector development in healthcare and imaging. There are clear synergies with the detector development group (many members are common to both) developing positron emission tomography, Ortho-CT, radiation therapy and dosimetry using particle physics detector techniques, that improve the performance of these important medical diagnostic and therapeutic instruments.

11) The applications for space exploration group uses particle physics detectors for radiation dosimetry in space, also in close synergy with the detector development group. Again this shows how particle physics detectors can be used in other areas of science.

12) The Computing group has been extremely successful at coordinating Grid and Cloud computing and High-Performance Computing in Portugal. They participate in international and EU-funded grid computing infrastructures, such as EGI (European Grid Initiative) and WLCG (World LHC Grid Computing), which supports the particle physics programme, but also has many applications outside of particle physics, with a large fraction of CPU time of these major national facilities devoted to other areas of science.

The plans of LIP for the future are all excellent, with an overall coordinating role of all particle physics in Portugal. This is essential to be able to have critical mass and to increase the visibility of Portuguese particle physics in large international collaborations. Applications of particle physics to society, such as medical, imaging, dosimetry and other areas of science, such as space, are also very strong, and LIP should be commended for this strategy. The LIP participates in 5 EU-funded ITN and COST actions, showing the internationalisation and networking of the group. The outreach and public understanding of science engagement programme by LIP is also excellent, increasing the visibility of particle physics in society. They organize an international Portuguese-speaking Teachers Education Programme, in collaboration with CERN, in which school teachers from many Portuguese speaking countries visit CERN and receive education and training on particle physics. Furthermore, LIP has strong collaboration with industry to enhance the technological capabilities of Portuguese industry and to encourage Portuguese industry to bid for CERN contracts. In summary, LIP is truly a Center of Excellence and should continue to lead particle physics research and innovation in Portugal.

RESEARCH Areas and Lines

Experimental particle and **astroparticle physics**

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

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

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

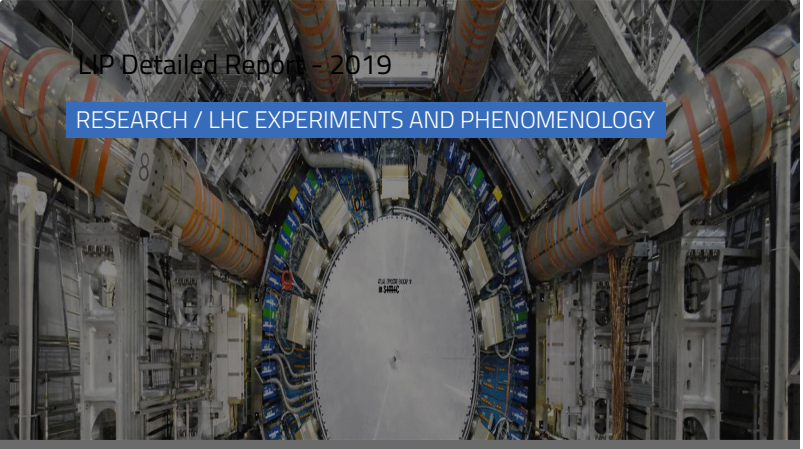
Computing

- Scientific Computing

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)

13 ***Researcher(s):***
Agostinho Gomes (85), Amélia Maio (30), António Onofre (15), António Pina (25), Filipe Veloso (100)[+], Helena Santos (85), Helmut Wolters (60), João Gentil (80), Marcin Stolarski (20), Miguel Fiolhais (30), Nuno Castro (50)[+], Ricardo Gonçalo (60), Rute Pedro (100)[+]

4 ***Technician(s):***
Filipe Martins (100), Luís Gurriana (78), Luís Seabra (100), Rui Fernandez (45)

8 ***PhD Student(s):***
Ademar Delgado (10), Ana Carvalho (100), Ana Peixoto (93)[+], André Pereira (33), Emanuel Gouveia (90), Maria Ramos (7), Susana Santos (67), Tiago Vale (93)[+]

6 ***Master Student(s):***
André Reigoto (10), Maura Teixeira (67), Pedro Lagarelhos (33), Ricardo Barrué (67), Ricardo Faria (17), Rui Martins (40)

1 ***Undergraduate Student:***
Bruno Rodrigues

21 ***Trainee(s):***
Alexandra Oliveira, Céu Neiva [x], Dmytro Ostapchuk, Filipe Cruz, Francisco Laranjinha, Gonçalo Fernandes, Hugo Miranda, Inês de Jesus Rebanda, Ivan Muñoz, José Abreu, Levon Abelian, Louie Larsen, Luís Neto, Maria João Portela, Nuno Morujão, Pedro Passos, Rebecca Clews, Rebecca Irwin, Rodrigo Gazola, Rudnei Machado, Tomás Ferreira

12 ***External collaborator(s):***
André Wemans, Artur Amorim de Sousa, Filipe Cuim, Gianpaolo Benincasa, Guiomar Evans, José Rufino, José Soares Augusto, Juan Antonio Aguilar Saavedra, Miguel Alves, Mikael Chala, Rui Santos, Susana Sério

Total FTE:
18.9

[x] Starting in 2020
[+] Participation in the Competence Centre on Simulation and Big data within the project BigDataHEP included here

Articles in international journals:
3 Direct contributions
4 Internal review by the team
85 Indirect contribution
Proposals, Yellow Reports and related studies:
5
Internal notes:
11 Notes
International conferences:
7 Oral presentations
2 Posters
6 Proceedings
National conferences:
1 Oral presentation
National or International meetings:
2 Oral presentations
2 Posters in International meetings
Collaboration meetings:
97 Oral presentations
Advanced Training Events:
5 Oral presentations
Seminars:
6 Seminars
37 Outreach seminars
Completed theses:
1 PhD
2 Master

Executive summary

The LIP Portuguese group was a founding member of the ATLAS Collaboration and has made important contributions to the detector and Trigger/DAQ design, construction and commissioning. The most important of these were in the TileCal hadronic calorimeter, the forward detectors and the jet trigger software. Since the beginning of LHC operations we have contributed to detector operation, performance studies, and physics analysis. We contributed to the Higgs boson discovery and are now measuring its properties. We are a reference in top quark physics studies and have exploited this expertise to lead several searches for new physics. We have made important contributions to the ATLAS heavy ion physics programme with the study of jets as probes of the quark-gluon plasma (QGP). In addition, we are contributing to the detector upgrades with responsibilities in the TileCal and trigger systems. Our members have occupied a number of coordination positions in the collaboration in most activities where the group is involved, from detector maintenance and operations to physics analysis and collaboration committees.
Last year the LHC started the Long Shutdown 2. The focus of the collaboration and our group was two-fold: on the one hand, continue the analysis of the full Run 2 dataset and, on the other one, implement the Phase-I Upgrade programme. In parallel, the work towards the Phase II Upgrade continues in full swing.

Sources of funding

PI	Code	Amount	Dates	Description
Helena Santos	IF/01586/2014/CP1248/CT0003	42.000 €	2015-01-01 / 2019-12-31	Expl. 2015 HS - IF/01586/2014/CP1248/CT0003
Patricia Conde	CERN/FIS-PAR/0008/2017	313.000 €	2017-07-01 / 2019-08-31	Collaboration in the ATLAS experiment
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

Total: 726.250 €

ATLAS

Lines of work and team organization

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

Physics Analysis

- Higgs physics (P. Conde, R. Gonçalo). Our goal is to study the Yukawa couplings of the Higgs boson to quarks which are accessible at the LHC (top and bottom), including spin and CP properties in the coupling vertices. For this, we are measuring the Higgs decaying to b-quark pairs in the associated production with a W or Z boson (VH production), and in association with top quark pairs (ttH).
- Precision measurements in the top quark sector (A. Onofre, F. Veloso). Our aims are to study the Vts vertex, through the measurement of the top decays to Ws, and the search for new physics phenomena above the TeV scale using top quark precision measurements in the context of an effective field theory approach. We are leading the latter in ATLAS, with one of the team members (N. Castro) being the contact person of the top working group for a global ATLAS combination in this context.
- Direct searches for new physics phenomena (N. Castro). We are searching for vector-like quarks, predicted by some of the extensions of the SM as a way to regulate the Higgs mass. We also lead the search for flavour changing neutral currents associated to the tZq vertex and the search for monotop events, which can be used to probe dark matter production at the LHC. Our group is also contributing since the very start to a new effort at the ATLAS Collaboration to use advanced anomaly detection tools to search for new physics phenomena in data being as independent as possible from the details of the new physics signal.
- Heavy ion physics (H. Santos). Our long term goal is to understand the mechanism of the jet energy loss in the QGP using jets as probes. Currently we are studying the 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 contribute to ageing studies of the scintillators and WLS fibres.
- Jet Trigger (R. Gonçalo). We have much expertise in jet reconstruction, hadronic calibration and real time algorithms. We contribute to the jet trigger operations, monitoring and development.
- Forward Detectors (P. Conde, N. Castro). We are leading the DCS of the ALFA and AFP detectors. In ALFA we are responsible for the full system and in AFP our responsibility is the vacuum, cooling and movement controls. In addition we contribute to the 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 organization.

Detector Upgrades

- TileCal Upgrade (A.Gomes, A. Maio). We were responsible for replacing MBTS fibres with more radiation-hard ones (Phase I) and for the production of the new TileCal high-voltage distribution system for the Phase II, in collaboration with Portuguese industry.
- High level trigger system (P. Conde, R. Gonçalo). We have two goals for the trigger upgrade. One is the development of parallel real time algorithms that use General Purpose Graphical Processing Units (GPU) as hardware accelerators. The second is the Hardware Track Trigger (HTT), where we will contribute to simulation and performance studies and the production of a communication board.

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)

Stated objectives for past year

Physics studies

Higgs physics:

- Contribute to the measurement of the high pT cross section of the $H \rightarrow bb$ decay in VH production, with responsibility on the fits an optimization of boosted taggers.
- Develop CP-sensitive analysis of ttH production with ATLAS data
- Finish the publication of the sensitivity studies to bump searches in ttH and anomalous couplings in the Hbby vertex.

Precision measurements in the top quark sector:

- Continue 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:

- Lead and actively contribute to the search for vector like quarks in the multilepton channels using the full Run 2 data.
- Lead and actively contribute to the interpretation of the vector like quark searches in terms of alternative production and decay modes.
- Lead and actively contribute to the search for flavour changing neutral currents in the tZq vertex using the full Run 2 data.
- Contribute to the combination of the ATLAS searches for dark matter using 2015+2016 data.

Heavy Ion physics:

- Focus on the study of heavy flavour jet production, benefiting from the b-tagging techniques developed in our group.

Detector maintenance, operation and upgrade

Forward Detectors:

- ALFA DCS: lab and production system upgrade following the general ATLAS DCS guidelines for Long Shutdown 2 (LS2) including software migrations, new DCS machines and moving OPC DA from Windows Virtual machine to OPC UA on Linux. More oriented ALFA DCS upgrades including PLC integration, database integration and motherboard readout.
- AFP DCS: production system upgrade following ATLAS DCS guidelines for LS2 and general upgrades for the cooling, movement and vacuum systems.
- Finish and validate the first trigger chains to select di-jet events in central exclusive production.
- Measure the AFP trigger efficiency with 2017/18 data.

TileCal:

- Maintain reliability of the DCS during operations and improve functionality when needed.
- Study the ageing of the TileCal scintillators using the calibration systems and pp collisions data, to determine the expected light loss at the end of the High-Lumi LHC phase.
- Migration of the DCS software for the new operating system and new WinCC versions
- Migration from SVN to Git (software supervision tool)
- Test and implementation of a DCS component for the Cesium Calibration System – ongoing work
- Preparation of the DCS software for the insertion of the Demonstrator in TileCal.
- Update Tile Muon Detection Board simulation and offline software to take into account the new Muon Small Wheel, being installed during LS2.

In what corresponds to the TileCal upgrade:

- Finish the DCS requirements document for HL-LHC.
- Production and tests of a prototype of the 48-channel HVRemote board, to be installed in the TileCal demonstrator module in May.
- Design and production of the HV and LV power boards for the HVremote boards.
- Design and production of a crate to house the HVRemote boards and the primary HV boards.
- Production and test of the 32-channel HVRemote board for the extended barrel detector.
- Develop test benches for the quality control of the cables and the high voltage regulation systems of the upgrade of the TileCal.
- Develop the DCS software for the control of the HVRemote board using a system on chip Zync-7020.
- Aluminization and quality control at LOMaC of green/red WLS fibres to readout the blue/green scintillators for the MBTS Phase I Upgrade.

Trigger upgrade:

- Contribute to the upgrade of the jet trigger software during the LHC shutdown.
- Finish the study of expected HTT performance for the HL-LHC benchmark channel boosted di-Higgs production in the 4b final state.
- Implement the fast simulation for HTT.
- Study new possibilities to further improve the performance of the GPU calorimeter trigger prototype and reduce the data transfer overheads.
- Prepare future production of the communications board for HTT.

Outreach and advanced training

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

Achievements and responsibilities during the past year

Physics

Higgs:

- Contributed to the search for boosted H→bb decays in VH associated channel (publication in preparation), with the optimization of the boosted jet reconstruction and identification, as well as identification of additional event selection variables.
- First study of the modelling of angular variables to measure the hWW vertex spin/CP structure in the VH associated production channel and expected sensitivity to anomalous couplings with the Run 2 data. A master thesis is being finalized on this topic.
- Contributed to the analysis of ttH with H→bb decays, to be published soon. Our group established methods to achieve sensitivity to the CP nature of the ttH vertex and was responsible for leading aspects of the analysis, including the determination and modelling of background sources, and the statistical analysis.
- Started to work on a continuous double b-tagger in the boosted regime to increase available figure of merit of analyses with two b-quarks in the final state. In order to avoid biases due to discrepancy between real data and Monte Carlo used for b-tagger training, taggers with anomaly detection and/or quality control are being investigated.

Top quark precision measurements:

- The effective field theory interpretation of the ATLAS top quark results is progressing, with first internal results obtained and being discussed by the collaboration.
- Studied the ATLAS sensitivity for the FCNC tZq vertex at the high luminosity phase of the LHC.

Direct searches for new physics phenomena:

- The search for FCNC tZq vertex search using using the full run-2 dataset is progressing with a combined effort targeting both production and decay mode. This effort is a collaboration between the LIP, Roma Tre and Tbilisi groups.
- The search for vector-like quarks (T or B) in the Zt/b+X channel using the full run-2 dataset is currently under collaboration review. This version of the analysis explores the boosted regime, with the top quark, W, Z and Higgs being tagged using deep learning techniques and is a combined effort by the LIP, Dortmund and UT-Austin groups. The NPA analysis code, developed by LIP, is now being used by all the analysis teams in this search.
- The global combination of the ATLAS searches for dark matter (paper in preparation) using 2015+2016 data was published, with the LIP group being responsible for the monotop analysis.

Heavy Ions:

- Study of the b-jet trigger performance.
- Prepared Monte Carlo simulation of b-jets produced in Pb+Pb collisions.
- Study of the reconstruction performance of b-jets produced in pp collisions at 5 TeV.

Detector-related activities

TileCal DCS:

- Updated and maintained the DCS software and hardware in production system, test beam and laboratories. Created git repositories for the DCS software used in the laboratories and test beam.
- Assisted detector maintenance teams during the shutdown.
- Initial integration of the Phase II Demonstrator in the production control system.

TileCal calibration and performance:

- Coordination of TileCal Calibration.
- Main analyser of the TileCal Optics robustness, studying the light loss of scintillators and fibres due to radiation damage using data from the calibration systems and pp collisions. Current results show that more than 60% of the TileCal cells are expected to have a relative light yield of more than 85% at the end of the HL-LHC.
- Optimized the methods of laser data analysis and provided the calibration for the ATLAS 2018 data reprocessing.
- Main editor of an internal note documenting the activities and results of the laser calibration during the LHC run-2.
- Undergoing study of the stability and linearity of the laser system and working on its documentation.

Upgrade activities:

- Aluminization of the top end of the last 600 WLS optical fibers for the instrumentation of the TileCal minimum bias trigger scintillators counters for the Phase I Upgrade done at LOMaC. A light yield dispersion of <6% and a mirror reflectivity coefficient better than 75% were measured for the aluminized fibers.
- Tested the HV cables, connectors and HVremote board prototype with 24 channels for the Phase II Upgrade. Cables installed in the test Demonstrator at CERN.
- Designed, produced and tested the 48 channel prototype of HVRemote board.
- Designed the HV supplies board and established guidelines for the crate backplane.

- Designed and implemented the communications and control test system for the HVRemote board using a Raspberry Pi.
- Passed the Preliminary Design Review of HVbus, HVremote boards and cables.
- Updated the simulation and offline TMDB software for Run-3 settings. Tests and validation started.
- Established the TileCal DCS requirements as part of the "ATLAS Phase-II Upgrade Project - DCS: Requirements Document for HL-LHC" - Publication in preparation.

Forward Detectors:

- Maintained the ALFA and AFP DCS production systems.
- Most effort was dedicated to tests, installation of new DCS machine and software migration in ALFA DCS test system.

Jet trigger maintenance, operation and upgrade:

- Implemented the first version of the HTT fast simulation.
- Contributed to the performance studies of HTT, focusing on di-muon triggers for the selection of the $Z \rightarrow \mu\mu$ benchmark channel.
- Supported the ATLAS trigger operation with software validation shifts.
- Reinitiated the effort on the study of calorimeter reconstruction algorithms to be run on GPUs, in the framework of the software trigger R&D for the Phase II Upgrade.

Distributed computing

- Excellent operation of the Iberian region and Portuguese Tier2.
- Improvement of the distributed computing monitoring infrastructure.

Education and outreach

The group participated in several outreach activities including secondary school MasterClasses in many different locations in Portugal, presentations and seminars for the general public and high school students/teachers. In addition, we contributed to the following activities for university students:

- The hands-on workshops organized by LIP in Costa da Caparica (February).
- Contributed to the organization, lectures and hosted 16 students in the LIP summer students internship in Lisbon, Coimbra and Minho, as well as 4 summer students from Liverpool University.

Responsibility positions within the ATLAS Collaboration (in 2019)

- P. Conde Muíño, member of the ATLAS Executive Board.
- H. Wolters, coordinator of the Iberian Cloud.
- H. Wolters, responsible for the Portuguese Federated Tier2 in the Iberian Cloud Squad.
- N. Castro, contact person for the effective field theory interpretations of the Top Quark Working Group (since September 2017).
- N. Castro, contact editor for the search for monotop events plus missing energy.
- A. Peixoto, analysis contact for the search for tZ production via FCNC.
- T. Vale, analysis contact for the searches for VLQ.
- N. Castro, member of the ATLAS Physics Office and coordinator of the gitlab integration team.
- F. Martins, TileCal DCS coordinator.
- L. Seabra, AFP DCS co-coordinator, ALFA DCS responsible.
- P. Conde, member of the Panel for Operation Task Sharing.
- R. Pedro, TileCal Calibration co-coordinator.
- H. Wolters, member of the ATLAS International Computing Board

Editorial Boards

Members of our group participated in 6 ATLAS Editorial Boards: H. Santos (2, one as chair), F. Veloso (1), P. Conde (2, 1 as chair), N. Castro (1, as chair).

Lines of work and objectives for next year

Physics studies

Develop a comprehensive strategy for the Run 3 analysis within the group, exploring our areas of expertise and developing synergies with the LIP phenomenology group and competence center on simulation and big data, as well as with international collaborators.

Higgs physics:

- Finish the measurement of the high pT cross section of the H → bb decay in VH production. Develop the analysis of the spin/CP properties of the hWW vertex in the WH associated production channel, with the full Run 2 dataset and the best calibrations/recommendations from the Combined Performance groups.
- Finish the CP-sensitive analysis of ttH production and make a strong contribution to the ATLAS analysis of this channel with full Run 2 data.

Precision measurements in the top quark sector:

- 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.

Heavy Ion physics:

- Focus on the study of heavy flavour jet production, benefiting from the b-tagging techniques developed in our group.

Detector maintenance, operation and upgrade

Forward Detectors:

- ALFA DCS: finish the lab and 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.
- Finish and validate the first trigger chains to select di-jet events in central exclusive production.
- Measure the AFP trigger efficiency with 2017/18 data.

TileCal:

- Provide assistance to the detector's maintenance during the LS2 period and report any issues with the hardware of the detector.
- Migration of the DCS system to new machines and update of the software for the newer versions of the operating system and WinCC.
- Re-design the DCS component for the high voltage crates.
- Improve the logging of the control scripts.
- Improve the study of the ageing of the scintillators and WLS fibres investigating possible dose rate effects and developing model of light loss as a function of expected dose, to extrapolate current observations to the High-Lumi LHC phase.
- Coordination of Calibration: prepare calibration procedures and operations for the next LHC run-3, expected to start in May 2021.
- Finish the internal note of laser calibration activities in run-2 as support for laser run-2 paper and TileCal run-2 operation paper.
- Lead an editorial team to write the Laser run-2 paper.

In what corresponds to the TileCal upgrade:

- Finish the test of the HVRemote board prototype 2 with 48 channels.
- Finish the design of the prototype 3 of HVRemote board.
- Finish the design of the crate to house the HVRemote boards and the HVsupplies boards. Finish the design of the associated supply and control boards.
- Finish the tests of the HV cables and connectors.
- Develop test benches for the quality control of the HV boards and cables
- Produce 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
- Continue the development of the DCS software for the control of the HVRemote crate using a system on chip Zync-7020.
- Conclusion of the TMDB simulation and offline software tests and validation.

Jet Trigger preparations for the Run 3:

- Study the performance of the new particle flow jet reconstruction algorithms at trigger level.
- Implementation of shallow copies of the jet trigger containers to avoid multiple copies/storage of the same information.

Trigger Phase II Upgrade:

- Contribute to the HTT effort:
  - Finish the studies of expected HTT performance for the HL-LHC.
  - Finish the fast simulation software for the HTT tracking co-processor
  - Install at LIP a testing station for HTT electronics boards, to allow participating in prototyping and debugging of this system
  - Prepare future production of the communications board for HTT.
- Contribute to the new Trigger Accelerators effort:
  - Port the TAC (Topo Automaton Clustering, the GPU version of the TopoCluster reconstruction) to the new AthenaMT framework.

- Performance study of TAC in the new framework (no client-server architecture), identification of the limitations and optimization.
- Finish performance study and optimization of the cluster splitting phase in the old prototype (client-server architecture) and publish the results.

Distributed computing

- Migration of the ADC Site Status Board to the new Grafana monitoring framework.
- Updating the Portuguese Tier2 operation to the changes in the ATLAS computing model for Run3.

Outreach and advanced training

We will maintain the same 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 strategic plans of the ATLAS Portuguese team for the next five years take into account the schedule of the LHC and the main unanswered questions that remain in Particle Physics.

In terms of proton-proton collisions physics, the main objectives are focused on precision measurements of the Higgs couplings (in particular to quarks), including spin/CP properties of the interaction vertices, precision measurements in the top quark sector and direct searches for new physics. Both, the studies of the top quark and Higgs properties, are fundamental to probe the limits up to which the SM provides an accurate description of nature. The strategy is complemented with direct searches for new exotic particles, such as vector-like quarks, foreseen by many new physics theories as a way to regulate the Higgs boson mass.

In what corresponds to the Heavy Ion physics programme, the main group objective for the next few years is to probe the nature of the energy loss of the partons as they traverse the QGP by measuring the modification of heavy quark production.

The group will continue its commitments in detector maintenance and operation activities in the TileCal, the jet trigger system and the forward detectors. In addition, a strong effort will be dedicated to the detector upgrades for the TileCal and trigger systems. In what regards to the former, the main effort will be the full production of the new high voltage distribution system for the Phase II Upgrade of TileCal, that involves the Portuguese industry, and the continuous upgrades of the detector control system. Systematic studies of the ageing of the optical components (scintillators and fibres) will complete this effort. On the trigger side, the focus will be on the software, with the development of advanced real time algorithms that use hardware accelerators (such as general purpose Graphical Processing Units, GPU). This effort will be complemented with simulation and performance studies of the Hardware Track Trigger (HTT) and the production of a communication board for the HTT. We will exploit our expertise on DCS to contribute to the development of the HTT control system.

SWOT analysis

Strengths

The LIP group is a well-established member of the ATLAS Collaboration, with many years' worth of important contributions to the experiment and with collective know-how in several important areas. Our main strengths are in the domains of calorimetry, DCS, software triggers and physics analyses. The group has experimental labs in Lisbon (LOMaC), dedicated to instrumentation in calorimetry, on the preparation, quality control and characterization of optical wavelength shifting and scintillating fibres, plastic scintillators and photomultipliers. There is also expertise on electronics and advanced computing.

In the area of physics analyses we have made important contributions to the Higgs discovery and properties studies, to jet suppression in heavy ion collisions, and our long expertise in top quark physics has put us in a leading role in many measurements of the top quark properties and searches for exotic new physics phenomena.

The internal reflection concerning a comprehensive strategy for the Run 3 analysis, to be carried out this year, will lead to a mature group wide strategy for the physics exploitation of the Run 3, boosting the potential impact of the group.

Weaknesses

Despite the new students attracted, it is important to ensure a stable flow of master/PhD students in order to maintain effort in the different activities. We also have a reduced number of postdocs and early career researchers, reflecting a national problem in scientific employment, which limits the possibility for expanding the number of activities and supervisions.

Opportunities

We are a national team with connections to many of the universities in the country. The recent appointments as professors of three members of the group (one at IST, one at Coimbra University and another one at Minho University), has significantly ameliorated our difficulties in maintaining senior human resources, and place us in an optimal situation to strengthen our connection to the universities and attract new students. The start of a new Portugal-CERN PhD grants program, with 15 PhD grants per year being awarded in the next 3 years, will allow excellent funding opportunities for high-level students.
The new challenges of the LHC upgrade and the large amount of data collected during Run 2, open new possibilities for a sustainable growth of the group. In addition, the growth in LIP of phenomenology and data science fields provides an excellent opportunity for synergies.

Threats

The funding structure in Portugal continues to be unstable and poorly adjusted to large continuing projects. The humanpower situation of the group continues to be delicate, in particular in what corresponds to postdocs. The situation may become critical if key persons leave the group.

The ability to profit from the new Portugal-CERN PhD grants deeply relies on the ability to attract new high-level students to the group. A coordinated strategy for students supervision and proposal of thesis topics must be adopted.

ATLAS

Publications

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

- *"Search for large missing transverse momentum in association with one top-quark in proton-proton collisions at $sqrt{s}=13$ TeV with the ATLAS detector"*, ATLAS collaboration, JHEP 05 (2019) 41
- *"Constraints on mediator-based dark matter and scalar dark energy models using sqrt(s) = 13 TeV pp collision data collected by the ATLAS detector"*, ATLAS collaboration, JHEP 19 (2019) 142
- *"Role of the t(t)over-barh rest frame in direct top-quark Yukawa coupling measurements"*, Andrea Ferroglia, Miguel C. N. Fiolhais, Emanuel Gouveia, and António Onofre, Phys. Rev. D 100, 075034

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

- *"Search for vector-boson resonances decaying to a top quark and bottom quark in the lepton plus jets final state in pp collisions at $sqrt{s}$ = 13 TeV with the ATLAS detector"*, ATLAS collaboration, Phys.Lett. B788 (2019) 347-370
- *"Measurement of the t(t)over-barZ and t(t)over-barW cross sections in proton-proton collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Phys. Rev. D 99 (2019) 072009
- *"Search for long-lived neutral particles in pp collisions at root s=13 TeV that decay into displaced hadronic jets in the ATLAS calorimeter"*, ATLAS Collaboration, Eur. Phys. J. C 79 (2019) 481
- *" Measurement of the azimuthal anisotropy of charged-particle production in Xe+Xe collisions at 5.44 TeV with the ATLAS detector"*, ATLAS Collaboration, arXiv:1911.04812

6 International Conference Proceedings

- *"Recent highlights in top quark and Higgs boson physics from the LHC"*, R. Gonçalo on behalf of the ATLAS and CMS Collaborations, J. Phys.: Conf. Ser. 1137 011001 (2019); ATL-PHYSPROC-2018-109, in Proceedings of BEACH 2018 – XIII International Conference on Beauty, 17 – 24 June
- *"Overview of Heavy Ions from the ATLAS Experiment"*, Helena Santos, on behalf of the ATLAS Collaboration, Acta Physica Polonica B, Vol. 50 (2019)

6 International Conference Proceedings

- *"Results on quarkonia production in Heavy Ion collisions from the ATLAS Experiment"*, Helena Santos (for the ATLAS Collaboration), J PHYS CONF SER 1137 (2019) UNSP 012046
- *"Measurements of Higgs boson production using decays to two b-quarks with the ATLAS detector"*, R. Pedro, ATL-PHYS-PROC-2019-119
- *"Jet Measurements in Heavy Ion Collisions with the ATLAS Experiment"*, Helena Santos, Proceedings of Science (PoS) ATL-PHYS-PROC-2019-127
- *"The ATLAS Hardware Track Trigger design towards first prototypes"*, A. L. Carvarlho on behalf of the ATLAS Collaboration, PoS (LeptonPhoton2019) 166.

5 Yellow Reports and related studies

- *"Higgs Physics at the HL-LHC and HE-LHC", M. Bengala, A. Costa, M. Fiolhais, M. Gallinaro, R. Gonçalo, A. Onofre, R. Santo, G. Strong et al.: , CERN-LPCC-2018-04, arXiv:1902.00134*
- *"Report on the Physics at the HL-LHC and Perspectives for the HE-LHC"*, ATLAS and CMS Collaborations, CERN Yellow Reports: Monographs, [S.l.], v. 7, p. 1, dec. 2019. ISSN 2519-8076
- *"FCC-hh: The Hadron Collider: Future Circular Collider Conceptual Design Report Volume 3"*, FCC Collaboration, Eur. Phys. J.-Spec. Top. 228 (2019) 755-1107
- *"HE-LHC: The High-Energy Large Hadron Collider Future Circular Collider Conceptual Design Report Volume 4"*, the FCC Collaboration, Eur. Phys. J.-Spec. Top. 228 (2019) 1109-1382
- *"Standard Model Physics at the HL-LHC and HE-LHC"*, Azzi Patrizia, F. Veloso et al, CERN-LPCC-2018-03, arXiv:1902.04070

8 Internal notes

- *"Search for invisible particles produced in association with single-top-quarks in proton-proton collisions at sqrt(s)=13 TeV with the ATLAS detector"*, M. Alhroob et al., ATL-COM-PHYS-2017-693
- *"Searches for Dark Matter with the ATLAS Detector at the LHC"*, J.K. Behr et al., ATL-COM-PHYS-2017-1031
- *"ATLAS Data Quality Operations and Performance during Run 2"*, H. Santos et al,, ATL-COM-DAPR-2019-001
- *"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
- *"b-jet triggers in Pb+Pb collisions"*, H. Santos, ATL-COM-PHYS-2019-607
- *"Measurement of the ttH production cross-section in the H→bb decay channel using 139 fb−1 of pp collision data at sqrt{s} = 13 TeV : Supporting note for ANA-HIGG-2018-11"*, Emanuel Gouveia, Ana Luisa Carvalho, Ricardo Gonçalo, António Onofre, ATL-COM-PHYS-2019-1378
- *"Global Sequential Calibration with the ATLAS Detector in Proton-Proton Collisions at sqrt(s) = 8 TeV with ATLAS 2012 data"*, P. Conde Muino, J. Gentil, A. Maio, J. Maneira, M. Sousa, et al., ATL-COM-PHYS-2014-753
- *"Determination of jet calibration and energy resolution in proton-proton collisions at sort(s)= 8 TeV using the ATLAS detector"*, P. Conde Muino, J. Gentil, A. Maio, J. Maneira, M. Sousa, et al.ATL-COM-PHYS-2017-164,

3 Collaboration notes with internal referee

- *"Sensitivity of searches for the flavour-changing neutral current decay $t\rightarrow qZ$ using the upgraded ATLAS experiment at the High Luminosity LHC"*, The ATLAS Collaboration, ATL-PHYS-PUB-2019-001
- *"ATLAS Phase-II Upgrade Project - DCS: Requirements Document for HL-LHC"*, Stefan Schlenker, Revital Kopeliansky, Filipe Manuel Pedro Martins, Massimo Corradi, Junjie Zhu, Yasuyuki Horii, Riccardo Vari, Paris Moschovakos, Matteo Beretta, Giuseppe Francesco Tartarelli, Sven Menke, Federico Lasagni Manghi, Davide Caforio, Jonas Strandberg, Susanne Kersten, Peter William Phillips, Ewa Stanecka, ATL-COM-UPGRADE-2019-013

- *"Calorimeters for the FCC-hh"*, C. Neubuser, R. Goncalo, J. Gentil, CERN-FCC-PHYS-2019-0003

Presentations

8 Oral presentations in international conferences

- Helena Santos: *"Jet Measurements in Heavy Ion Collisions with the ATLAS Experiment"* , 2019-01-01, EPS-HEP 2019, Ghent - Belgium
- Patricia Conde: *"Overview of Higgs Physics Results from ATLAS"* , 2019-01-16, COST Workshop on Higgs and Flavour Physics: Present and Future, IST Lisbon
- Filipe Veloso: *"FCNC and EFT interpretations at LHC"* , 2019-05-23, SUSY 2019, Corpus Christi Texas USA
- Helena Santos: *"Overview of Heavy Ions from the ATLAS Experiment"* , 2019-07-02, Epiphany 2019, Kracow – Poland
- Rute Pedro: ***"Measurements of Higgs boson production using decays to two b-quarks with the ATLAS detector"***, 2019-07-11, EPS-HEP Conference 2019, Ghent, Belgium
- Nuno Castro: *"Top-quark FCNC in production and decay processes"* , 2019-09-23, Top 2019 - International Workshop on Top Quark Physics, Beijing, China
- Helmut Wolters: *"Past and Future Challenges for Distributed Computing at the ATLAS Experiment on the Iberian Peninsula"* , 2019-09-25, IBERGRID 2019, Santiago de Compostela, Spain
- Tiago Vale: *"Data Science in High Energy Physics"*, 2019-09-25, Ibergrid - 10th Iberian Grid Conference, Santiago de Compostela, Spain

2 Poster presentations in international conferences

- Ana Carvalho: *"The ATLAS Hardware Track Trigger Design towards first prototypes"*, 2019-08-05, Lepton Photon 2019, Toronto, Canada
- Agostinho Gomes: *"Upgrade of the ATLAS Tile Calorimeter High Voltage System"*, 2019-09-02, TWEPP 2019, Santiago de Compostela

2 Oral presentations in international meetings

- Patricia Conde: ***"Physics with the ATLAS Forward Detectors",*** 2019-04-26, Second LIP-IGFAE Workshop, Santiago de Compostela
- Tiago Vale: ***"Rare event detection in High Energy Physics",*** 2019-09-20, UT Austin Portugal Program 2019 Annual Conference, Braga

2 Poster presentations in international meetings

- Ana Peixoto: "Search for flavour-changing neutral currents tZq interactions in proton-proton collisions at 13 TeV collected with the ATLAS detector", 2019-02-11, Poster session at the ATLAS Week, CERN
- Filipe Martins: "Detector Control System for TileCal Phase II", 2019-06-17, Poster Session ATLAS Week, CERN

1 Presentations in national conferences

- Nuno Castro: *"The Portuguese participation in the upgrade of the Large Hadron Collider at CERN"*, 2019-07-09, Encontro Ciência 2019, Lisboa

5 Oral presentations in advanced training events

- Nuno Castro: *"Probing the Standard Model and Beyond at the LHC"*, 2019-02-11, 4th Lisbon mini-school on Particle and Astroparticle Physics, Costa da Caparica, Portugal
- Emanuel Gouveia: *"Search for a CP-odd top quark Yukawa coupling with the ATLAS experiment"*, 2019-07-01, IDPASC and LIP PhD student workshop, Braga
- Ana Peixoto: *"Search for flavour-changing neutral currents tZq interactions in proton-proton collisions at 13 TeV collected with the ATLAS detector"*, 2019-07-01, 5th IDPASC/LIP PhD Students Workshop, Braga (Portugal)
- Tiago Vale: *"Search for heavy fermions with the ATLAS experiment"*, 2019-07-01, 5th IDPASC Workshop, Braga (Portugal)
- João Gentil: *"Hands on Particle and Light For Life (Workshop IDPASC/LIP)"*, 2019-07-10, Detecção de radiação com cintiladores/Radiation detection with scintillators,

6 Seminars

- Helena Santos: *"Heavy Ions Results from ATLAS in Run 2 of LHC"*, 2019-02-14, LIP Seminar, LIP Lisbon
- Patricia Conde: *"The Higgs boson: what do we know about it?"*, 2019-03-06, Colloquium, IST Physics Department
- Ricardo Gonçalo: "Introduction to Higgs Physics at the LHC" , 2019-04-02, IDPASC - Physics at the LHC, LIP
- Patricia Conde: "Results from the Higgs Searches at the LHC" , 2019-04-08, Physics at the LHC, LIP
- Ricardo Gonçalo: ***"Latest news from the Higgs Front"***, 2019-05-15, FCUL Seminar, FCUL
- Ricardo Gonçalo: *"Physics at the limit: The ATLAS Experiment at the LHC"*, 2019-12-04,Café com Física, University of Coimbra

37 Outreach seminars

- Ricardo Gonçalo: *"O Vazio e o Bosao de Higgs"*, 2019-01-25, O Espaço vai à Escola 2018 , Escola Secundária José Gomes Ferreira
- Ricardo Gonçalo: *"O Universo da Fisica de Particulas"*, 2019-01-30, Diálogos com Cientistas - Desafios nas Ciências Físicas e Biológicas, Oliveira do Bairro
- Filipe Veloso: *"Partículas elementares e forças fundamentais: o LHC"*, 2019-02-12, , Escola Secundária Frei Rosa Viterbo, Sátão
- Ricardo Gonçalo: *"Higgs hands-on and research opportunities in LIP ATLAS group"*, 2019-02-12, LIP/CFTP Mini-school of Particle Physics, Costa da Caparica
- Patricia Conde: *"Working in a large scientific collaboration"*, 2019-02-26, International Brain Laboratory Postdoc Summit, Champalimaud Centre for the Unknown Lisbon
- Ricardo Gonçalo: *"O LHC do CERN - a maquina dos infinitos"*, 2019-02-26, Public lecture during ParticleFace COST action workshop, Centro Rómulo de Carvalho, University of Coimbra
- Ricardo Gonçalo: *"Caçadores de Particulas - a fisica a mais alta energia"*, 2019-03-02, National Physics Students Meeting, IST, Lisbon
- Ana Peixoto: *"O Universo e a Física de Partículas"*, 2019-03-08, International Masterclasses on Particle Physics, Braga (Portugal)
- Ricardo Gonçalo: *"Caçadores de Partículas"*, 2019-03-12, O LIP Vai, Academia Sta. Cecília
- João Gentil: *"15ª International Masterclasses in Particle Physics"*, 2019-03-13, Detectores e Aceleradores, UTAD Vila Real
- João Gentil: *"15ª International Masterclasses in Particle Physics"*, 2019-03-14, Detectores e Aceleradores, IPB, Bragança

- Ricardo Gonçalo: *"O Bosao de Higgs e eu"*, 2019-03-16, Física Fora da Academia, FCUL
- Filipe Veloso: *"Detectores e Aceleradores"*, 2019-03-20, 15.ª Masterclasses Internacionais em Física de Partículas, Coimbra
- Tiago Vale: *"A origem do Universo e o CERN da questão"*, 2019-03-21, PubhD Uminho #35, Braga (Portugal)
- Emanuel Gouveia: *"Como estudar as partículas? Aceleradores, detectores e actividade experimental: o bosão Z (e o bosão de Higgs)"*, 2019-03-22, International Masterclasses - Hands on particle physics, Braga
- Filipe Veloso: *"Partículas elementares e forças fundamentais: o LHC"*, 2019-03-23, 15.ª Masterclasses Internacionais em Física de Partículas, Aveiro
- João Gentil: *"15º International Masterclasses in Particle Physics"*, 2019-03-23, Detectores e Aceleradores, IPB, Beja
- Ricardo Gonçalo: *"Caçadores de Partículas"*, 2019-03-23, Phys. Dept. Alumni Event , Coimbra
- Ricardo Gonçalo: *"A Fisica de Particulas"*, 2019-03-26, International Particle Physics Masterclass, University of Azores
- Susana Santos: *"Caminho do Z"*, 2019-03-30, CERN MasterClasses, Coimbra, Portugal
- Patricia Conde: *"A Física de Partículas: de que é que somos feitos?"*, 2019-04-02, Escola Amélia Rei Colaço, Lisboa
- Ricardo Gonçalo: *"O vazio e o bosao de Higgs"*, 2019-04-03, O LIP Vai, E.S. Povoa Sta. Iria
- Ricardo Gonçalo: *"A Fisica Experimental de Particulas"*, 2019-04-06, International Particle Physics Masterclasses, FCUL, Lisboa
- Patricia Conde: *"A procura de Partículas no CERN"*, 2019-04-23, MasterClasses of Particle Physics, Evora
- Helena Santos: *"(pequenos) Big Bangs no LHC"*, 2019-05-08, Dia aberto da FCUL, Lisboa
- Nuno Castro: *"Do in nitamente pequeno ao in nitamente pequeno"*, 2019-05-16, , Escola Secundária do Marco de Canaveses
- Tiago Vale: *"Novos ingredientes do Universo"*, 2019-05-21, Pint of Science, Braga (Portugal)
- Ricardo Gonçalo: *"Dados livres do CERN: recursos educativos"*, 2019-05-31, VI Encontro Internacional da Casa das Ciências, FCUL, Lisboa
- Helena Santos: *"(pequenos) Big Bangs no LHC"*, 2019-05-31, , Escola Secundária Gomes Ferreira
- Helena Santos: *"(pequenos) Big Bangs no LHC"*, 2019-06-03, , Escola Secundária de Castro Verde
- Ana Peixoto: *"What is the nature of our universe? What it is made of?"*, 2019-08-06, AstroCamp Summer School, Paredes de Coura (Portugal)
- Nuno Castro: *"A experiência ATLAS"*, 2019-09-05, 13th Portuguese Language Teacher Programme, CERN
- Ricardo Gonçalo: *"O Vazio e o Bosao de Higgs"*, 2019-10-10, ESERO - O Espaço vai à Escola 2019, Escola Luís de Camões
- Nuno Castro: *"Física de Partículas: a ponte entre o in nitamente grande e o in nitamente pequeno"*, 2019-10-16, IX Ciclo de Conferências Cientí cas, Vila Nova de Famalicão
- Ricardo Gonçalo: *"O Vazio e o Bosao de Higgs"*, 2019-11-08, ESERO - O Espaço vai à Escola 2019, Escola Luís de Camões
- Ricardo Gonçalo: *"Investigação no DF: o LIP e a Experiência ATLAS do LHC"*, 2019-11-19, Evento do núcleo de estudantes do departamentos e física da Universidade de Coimbra, NEDF, University of Coimbra
- Tiago Vale: *"Novos ingredientes do Universo"*, 2019-11-20, , Escola Secundária Alcaides de Faria, Barcelos

Theses

7 PhD

- André Pereira: *"An efficient particle physics data analysis framework for homogeneous and heterogeneous platforms"*, 2013-09-01 / 2019-05-27, (finished)
- 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)
- Maria Ramos: *"Interplay between collider and astrophysical signals of non-minimal composite Higgs models"*, 2017-11-15 , (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)

7 Master

- Rui Fernandez: *" Low Noise Power Supplies for the High Voltage Board of the TILECAL Calorimeter"*, 2019-11-08, (finished)
- Filipe Cuim: *"Functional Tester for High Voltage Boards of the TILECAL Calorimeter"*, 2019-12-02, (finished)
- Ricardo Barrué: *"Study of the ATLAS sensibility to anomalous Spin/CP components in the HWW vertex"*, 2017-01-01 / 2020-03-1, (ongoing)
- Maura Teixeira: *"Search for monotop events at the LHC using machine learning"*, 2018-10-01 , (ongoing)
- Pedro Lagarelhos: *"Prospects for the HL-LHC of the measurement of the top quark couplings in the ttbar semileptonic channel"*, 2018-09-16 , (ongoing)
- Ricardo Faria: *"Prospects for the HL-LHC of the measurement of the top quark couplings in the ttbar dileptonic channel"*, 2018-09-16 , (ongoing)
- Miguel Alves: *"Development of GPU-based Calorimeter Clustering algorithms for the ATLAS Upgrade"*, 2019-09-01 , (ongoing)

CMS

Collaboration in the CMS experiment at CERN

Principal Investigator:

Michele Gallinaro (100) [*]

8 ***Researcher(s):***
Jonathan Hollar (100), João Seixas (32), João Varela (83), Ksenia Shchelina (42), Nuno Leonardo (100), Pedrame Bargassa (100), Pietro Faccioli (22), Tahereh Niknejad (42)

2 ***Technician(s):***
José Carlos Silva (71), Rui Pereira da Silva (38)

4 ***PhD Student(s):***
Diogo de Bastos (100), Giles Strong (64), Mariana Araújo (79), Oleksii Toldaiev (100)

3 ***Master Student(s):***
Beatriz Ribeiro Lopes (90), Júlia Silva (21), Viorel Dubceac (92)

12 ***Trainee(s):***
Alberto Mosso, Alexandra Pardal, Artur Choi, Francisco Albergaria, Giuseppe Crupi, Gonçalo Vília, Henrique Borges, João Francisco Gonçalves, Matteo Magherini, Miguel Guerreiro, Timothée Cabos, Vítor Hugo Cardoso

14 ***External collaborator(s):***
Agostino di Francesco, André David, Anup Sikdar, Carlos Leong, Eliza Costa, Livio Fano, Luis Ferramacho, Miguel Silveira, Nicola De Filippis, Ozlem Ozludil, Pedro Ferreira da Silva, Pietro Vischia, Ricardo Bugalho, Sandro Fonseca

Total FTE:
12.9

(*) since February 2020

Articles in international journals:
5 Direct contribution
19 Internal review by the team
107 Indirect contribution
Proposals, Yellow Reports and related studies:
3
Internal notes:
11 Collaboration notes
International conferences:
6 Oral presentations
2 Proceedings
National or International meetings:
7 Oral presentations
5 Posters
Collaboration meetings:
78 Oral presentations
Advanced Training Events:
13 Oral presentations
Seminars:
8 Seminars
7 Outreach seminars
Completed theses:
2 Master

Executive summary

LIP is member of the Compact Muon Solenoid (CMS) Collaboration at the Large Hadron Collider (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: the discovery of a Higgs boson; the measurement of the top quark properties; the first observation of the rare $B_s \rightarrow \mu\mu$ decay; the measurement of the J/psi and Y polarizations; and the searches for a charged Higgs and a top squark.

The group contributed to the Phase 1 Upgrade of the experiment by building and installing new High-Speed Optical Links (oSLB-oRM) that interface the ECAL electronics to the trigger system. The CMS experiment took data in Run2 (2015-2018) at an energy of 13 TeV, and is currently undergoing maintenance and upgrades in preparation for Run3 that is expected to start in 2021. During the long-shutdown (LS2), the group has been involved in the preparation of the PPS and the ECAL detectors.

The LIP group is leading the development of the new PPS forward proton spectrometer, which took physics 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. Members of the group are presently serving as PPS Project Deputy Coordinator and coordinator of the Proton Physics Object Group (POG).

The group is actively involved and contributing to the physics analysis of the new data in the areas of Top quark, Higgs boson, B mesons, SUSY, quarkonia, heavy ions, and PPS physics. A member of the LIP group has coordinated the CMS B Physics group in 2014-2016.

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 measurement. In collaboration with industry, LIP provides a high-performance ADC ASIC for the ECAL front-end electronics resistant to radiation. The CMS upgrade includes also the complete replacement of the endcap calorimeters with a new high-granularity sampling calorimeter. LIP collaborates with industry by supplying a high-current low voltage regulator (LVR) resistant to radiation for the HGCAL frontend system.

It is worth noting that in the recent (July 2019) institutional Evaluation Report performed by an international review panel under the initiative of FCT, LIP received the highest quality grade (EXCELLENT). The contribution of the CMS group to this evaluation was explicitly recognized. Quoting the report "The CMS group, while small in size, is really outstanding and world-class".

Sources of funding

PI	Code	Amount	Dates	Description
Pedrame Bargassa	IF/00772/2014/CP1248/CT0002	50.000 €	2015-01-01 / 2019-12-31	Expl. 2015 PB - IF/00772/2014/CP1248/CT0002
João Varela	AMVA4NewPhysics - 675440	238.356 €	2015-09-01 / 2019-08-31	Advanced Multi-Variate Analysis for New Physics Searches at LHC
João Varela	CERN/FIS-PAR/0006/2017	345.000 €	2017-08-01 / 2019-07-31	Collaboration in the CMS experiment at CERN
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: 1.033.356 €

CMS

Lines of work and team organization

1) Proton-proton physics:

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

2) Heavy-ion physics:

The ultimate objective is the study of the quark-gluon plasma and the strong interaction, taking advantage of the collisions of lead beams at the LHC. The activity is led by a senior physicist and integrates other researchers and students.

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 High Luminosity.

4) Operation and maintenance of the ECAL and PPS detectors:

The LIP/CMS group has people based at CERN that 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 activities of the LIP-CMS group 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. He has 30 years of research experience both in the US (SLAC and Fermilab) and at CERN. The Co-PI is Nuno Leonardo. He has 20 years of research experience at Fermilab and CERN;
- The project "Collaboration in the Phase-2 Upgrade of the CMS experiment at CERN". The project PI is João Varela. He has 30 years of research experience at CERN. The Co-PI is Michele Gallinaro.

The 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 listed below:

- Group coordinator - J. Varela (until Feb 2020); M. Gallinaro (after Feb 2020)
- Deputy group coordinator - J. Seixas (until Feb 2020); J. Hollar and N. Leonardo (after Feb 2020)
- PI operation and physics data analysis – M. Gallinaro
- Co-PI operation and physics data analysis – N. Leonardo
- PI phase-2 upgrade - J. Varela
- Co-PI phase-2 upgrade - M. Gallinaro
- Physics Analysis Coordinators - M. Gallinaro, N. Leonardo, P. Bargassa, J. Hollar, J. Seixas, P. Faccioli
- Detector coordinators: PPS - J. Hollar
- 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 POG coordinator (Level-3), since 2019 (K. Shchelina)
- MTD/BTL electronics systems coordinator, since 2018 (J. Varela)

LIP group members participate in the following CMS structures:

- CMS Collaboration Board (J. Varela and J. Seixas), (M. Gallinaro and J. Varela - since March 2020)
- CMS Finance Board (J. Varela)
- CMS Publication Board (P. Faccioli, N.Leonardo)
- ECAL Executive Board (J.C. Silva)
- ECAL, PPS, MTD and HGCAL Institution Boards (J. Varela)
- 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.

Stated objectives for past year

The objectives of LIP/CMS group activities in 2019 were the following:

Task 1: Physics analysis:

1) Higgs physics
   1. Search for di-Higgs events in resonant and non-resonant modes in the di-tau and bbar final state (in the frame of the EU Marie-Curie network AMVA4NewPhysics);
   2. Study of Higgs bosons in the di-tau decay mode;
   3. Search for rare decays of the Higgs boson into quarkonium.

2) Electroweak physics

   1. Measurement of quartic gauge couplings in exclusive production using PPS.

3) B physics

1. Search for rare decays and measurement of heavy flavour production;
2. Investigate the flavour anomalies.

4) Top quark physics and New Physics searches

1. Cross section measurement in top quark decays including a tau lepton;
2. Search for Dark Matter associated to Higgs boson.

5) SUSY physics

1. Search for SUSY top squark in stop four-body decays.

6) Quarkonia and Heavy-ions

1. Measurement of the polarization of the χc1 and χc2 states.
2. Explore exclusive heavy flavor signals, as novel, sensitive probes of the QGP, using the PbPb data collected at the end of 2018.

Task 2: R&D Phase 2 Upgrade

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

1. Development of the second version of BTL ASIC in radiation tolerant CMOS 130 nm technology of TSMC (TOFHIR2), integration with detector modules based on LYSO crystals and SiPMs and beam tests (in collaboration with INFN Milan, CERN, Caltech, Princeton).
2. Development of the first prototype of the BTL Front-End board (BE) with the TOFHIR1 ASICs, and integration in the BTL Readout Unit in collaboration with ETHZ, Kansas State Univ, and CEA Saclay.

2) R&D in the ECAL frontend readout system

1. Characterization of the ADC 12-bit 160 MHz in the LiTE-DTU chip in collaboration with INFN Torino and with the participation of S3-Group.

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

1. 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

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

2) PPS

1. Preparation of the DAQ and online software for reinstallation of detectors in Run 3.

3) Physics objects development

1. Participation in the development and validation of the tau lepton reconstruction (Tau POG), forward proton alignment and high-level trigger in PPS.

4) Computing:

1. LIP/CMS interface with the LIP's Tier2 group.

5) General

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

Achievements and responsibilities during the past year

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

1) Proton-proton physics:

- *Top quark physics:*

Members of the group (PhD student A.Toldaiev, M.Gallinaro) have a leading role in the data analysis and preparation of the publication of the first Run2 results on the “Measurement of the top quark pair production cross section in the dilepton channel including a tau lepton”. The analysis was presented for the first time at the Lepton-Photon conference in Toronto (Aug 2019). The results have been published in JHEP. This work is the subject of the PhD thesis of A. Toldaiev.

- *Search for SUSY:*

The search for the 4-body decay of the lightest scalar top (stop) was performed using 2016 data by group members (post-doc fellow C.Cruz e Silva, P.Bargassa) who developed a unique search based on MVA approach. The results, obtained in collaboration with HEPHY (Vienna), were presented at the SUSY2018 conference by a group member, editor of the publication. The Run2 data analysis for the same search has started (PhD student D.Bastos, P.Bargassa). The “Search for stau and chargino pair production in di-tau final states” was published.

- *Search for double Higgs production:*

Regression and classification studies in di-Higgs production were pursued in 2018 with simulated CMS samples. Di-Higgs production search in the “tautaubb” final state is performed on CMS data using advanced "machine learning" analysis techniques. Work is developed in the context of the Tau Id POG, and Higgs HH working group. Projections for the expected sensitivity were estimated for the HL-LHC conditions and the results summarized in the Yellow Report. This activity was carried out in the framework of the EU Marie-Curie network AMVA4NewPhysics (PhD student G.Strong, M.Gallinaro). Two undergraduate students (M.Bengala and R.Santo) contributed to the work for the CERN Yellow Report.

- *Search for Dark Matter:*

Members of the LIP/CMS group (undergraduate student J.Goncalves, M.Gallinaro) pursued a search for Dark Matter produced in association with a Higgs boson. The Higgs boson decaying to a final state with four leptons is sought for in events with large missing transverse energy, possibly associated with the DM particles escaping the detector. The search was developed in collaboration with colleagues from Bari. The final results were submitted for publication.

- *Search for rare decays and measurement of heavy flavour:*

The $B \to \mu\ \mu$ analysis was pursued with Run2 data. The study of b-quark fragmentation fraction ratio, input to the measurement of the $B_s \to \mu\ \mu$ branching fraction, was performed (B.Alves Msc thesis). The analysis with the partial Run2 dataset (2016) has been concluded and submitted to the Journal. The group (PhD student O.Ozcelik, N.Leonardo) delivered the CMS HL-LHC projections of the $B \to \mu\ \mu$ analysis, and reported them in the CERN Yellow Report, submitted as input for ESPP update process.

- *Quarkonium polarization:*

Members of the LIP-CMS group (PhD student M. Araújo, P. Faccioli, J. Seixas) had a crucial role in the measurement of the polarization of the χc1 and χc2 states, in collaboration with CERN (C. Lourenço) and HEPHY (T. Madlener, I. Krätschmer); the corresponding paper has been accepted for publication in PRL.

- *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, which was published in 2018. Currently, members of the group are pursuing related analyses of two-photon production of W boson pairs (K.Shchelina, J.Hollar) and top quark pairs (MSc thesis B.Lopes, M.Gallinaro, J.Hollar) using PPS data. B. Lopes defended the MSc thesis (IST, December 2019, grade 19/20), entitled: "Search for exclusively produced top quark pairs at the LHC".

- *Studies of the $H \to \tau\tau$ process:*

Studies have been led to improve the multi-class NN for measuring the $H \to \tau\,\tau$ process in the semi-leptonic decays. In particular, specific NNs have been trained and studied to discriminate between signal and most challenging backgrounds, NNs whose outputs are then fed to the general classifying NN.

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 is playing a central part in the investigation of the first B meson signals in PbPb data. The analysis of the PbPb 2015 data (MSc student J.Silva, N.Leonardo) was published. The larger PbPb dataset collected in 2018 has been actively explored by the group, and in collaboration with MIT. The first observations of the B_s meson (J.Silva, N.Leonardo) and B^0 meson (G.Crupi, N.Leonardo) in nuclear collisions have been reported. The measurements of the production cross sections of B_s and B^+ mesons have been reported (with undergraduate students J.Silva, A.Pardal, J.Gonçalves). The relative suppression of B_s and B^+ mesons has been achieved in the MSc thesis of J.Silva (IST, October 2019, grade 19/20), entitled: "Probing the quark gluon plasma medium through B meson production measurements in PbPb collisions at the LHC".

3) 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 (K.Shchelina), and PPS high-level trigger (M.Araujo, C.Cruz e Silva). One member of the LIP/CMS group is coordinating the Proton POG.

4) PPS commissioning and operation

Under the leadership of a LIP member serving as PPS Project Manager (J.Varela), PPS collected over 100fb^{-1} of data from 2016-18 in Run2. The group had leading roles in the PPS DAQ system (J.Hollar) and the Timing detectors (M.Gallinaro). LIP made major contributions to the timing detector electronics, online software, and detector operations. Since 2018, one LIP member serves as Deputy Project Manager (J.Hollar). Members of the group are actively involved in physics analyses using PPS data (B.Lopes, K.Shchelina, M.Gallinaro, J.Hollar), and had leading roles in the first PPS physics paper.

5) CMS Phase 2 Upgrade (HL-LHC)

The R&D towards the Phase-2 upgrade carried by the group is organized in three areas:

1) 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);

2) 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);

3) 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.

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 read-out with silicon photomultipliers (SiPMs). The LIP group is responsible for the design and construction of the readout system of the Barrel Timing Layer. One member of the group is presently responsible for coordinating the development of the BTL Readout System.

Dedicated ASIC electronics is used to readout the SiPM arrays. The readout solution uses the new TOFHIR chip based on the PETsys TOFPET2 chip. The TOFHIR ASIC is being developed in the framework of the Collaboration Agreement KN436/EP between LIP and CERN. The microelectronics design of the TOFHIR circuits is sub-contracted to the Portuguese company PETsys. A first version of the chip (TOFHIR1) was implemented in the same technology as TOFPET2 (UMC CMOS 110nm) allowing the development of detector modules and the validation of system integration within a tight schedule. A preliminary evaluation of the TOFHIR1 ASIC was performed. The final version (TOFHIR2) is being developed in TSMC CMOS 130nm technology, which has increased radiation tolerance.

The frontend system has three types of boards, the Front-End 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 takes the responsibility for the design, production and testing of the FE Boards (1900 units). The first prototype of the Readout Unit based on TOFHIR1 was designed and fabricated and is in the process of being evaluated.

ECAL Readout System

The LIP-CMS group has an important role in the development and construction of the new ECAL Frontend 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 in a CMOS 65nm chip that implements additional digital logic and data transmission (LiTE-DTU chip). The chip was tested in the Q3-Q4 2019.

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 is developing a low voltage drop LVR ASICs resistant to radiation with the performance required by HGCAL under a contract established with CERN. The first LVR prototype chips are expected in 2020.

A study has been 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. The results of this study might be included, in the form of an MVA discriminant, among the L1 algorithms and help to diminish the very high PU rate while preserving the efficiency of VBF events which are of particular interest for the future physics to be searched at the HL-LHC.

6) Outreach & advanced training

Group members take part in outreach activities for high school and university students (IntMasterClasses, CERN visits, InsideViews, etc.). Group members have actively contributed to the Teachers School in Portuguese Language at CERN. One group member coordinated the LIP summer internship program and served as co-coordinator of Advanced Training at LIP. Group members gave multiple seminars and university colloquia, and facilitated lectures and hands-on tutorials.

Lines of work and objectives for next year

The LIP/CMS group activities in 2020 follow closely 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

1. Search for di-Higgs events in resonant or non-resonant modes in tau and bbar final states;
2. Study of Higgs bosons in the di-tau decay mode;
3. 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

- Measurement of the quartic gauge coupling ggWW using the PPS spectrometer.

3) B physics

- Search for rare decays and measurement of heavy flavour production and properties.

4) New physics in top like events

- Tau leptons and lepton-flavor universality studies in top quark events, and search for Dark Matter associated to the Higgs boson.

5) SUSY physics

- Search for SUSY top squark in four-body decays.

6) Quarkonia

- Precision measurement of the polarization of S-wave quarkonia.

7) Heavy-ion physics

- Further the exploration of heavy flavor signals as novel probes of the QGP.

Task 2: R&D Phase 2 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). Chip submission of version 1 in Q1 2020.

2) R&D in the ECAL frontend readout system

- Characterization of the LiTE-DTU chip, including tests of the ECAL frontend chain (collaboration with INFN Torino and CEA Saclay).

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

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

Task 3: Experiment operation and maintenance

1) ECAL

- Maintenance of the ECAL trigger and data acquisition system.

2) PPS

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

3) Physics objects development

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

4) Computing:

- LIP/CMS interface with the LIP'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 2020-24 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 Run3. The objective is to fully exploit the discovery opportunities offered by the LHC. The activity is organized in main physics domains, namely Higgs boson, Top quark, B mesons, Quarkonia, SUSY, PPS, and Heavy Ions, spanning from the search for new particles and phenomena beyond the SM to the precise measurements of the SM properties.

The group is responsible for the upgrade of the data acquisition system of the Precision Proton Spectrometer (PPS) in view of the Run3 data-taking, and will contribute to the maintenance and operation of the Precision Proton Spectrometer (PPS) and Electromagnetic Calorimeter (ECAL) sub-detectors.

Finally, the group will be strongly involved in the CMS Phase-2 Upgrade for the High-Luminosity LHC (HL-LHC), developing microelectronics for the readout systems of the MIP Timing Detector (MTD), Electromagnetic Calorimeter (ECAL), and High Granularity Calorimeter (HGCAL) in collaboration with the Portuguese industry, and taking the leadership in the development of the MTD readout system.

Physics

The SM does not provide answers to many fundamental questions in particle physics. Tiny deviations from the SM due to interactions with other forms of matter, including Dark Matter, could answer some very fundamental questions. Focus on precision measurements and search for rare processes may provide new hints in the understanding of Nature. 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 Run3, the CMS experiment expects to collect up to 300 fb^{-1}. The LIP/CMS group plans to contribute to the Higgs studies as well as to searches for new physics (NP) with these new data.

Detector Operation

Precision Proton Spectrometer (PPS)

With the LHC Run2 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 LS2, all detector components 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 baseline PPS timing readout is based on HPTDC mezzanine cards, for which LIP has led the design and production. LIP will also contribute to the testing and characterization of the timing readout chain, as well as the online software for both the timing and pixel tracking detectors, and the development of new high-level triggers.

Electromagnetic Calorimeter

In the CMS operations in the period 2020-2024, the group plans to continue to be responsible for the operation and maintenance of the ECAL Data Acquisition and Trigger hardware.

HL-LHC Phase2 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 retain the excellent performance of the detector in the harsh experimental conditions.

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.

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 and the leading role in several physics analyses. Leadership in different areas of the front readout systems of the Phase-2 Upgrade.

Weaknesses

Difficulty in attracting foreign researchers to Portugal.

Opportunities

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

Threats

Unclear career prospects for several senior physicists of the group.

Publications

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

- *"PICOSEC-Micromegas: Robustness measurements and study of different photocathode materials"* , M. Gallinaro et al., J.Phys.Conf.Ser. 1312 (2019) no.1, 012012
- *"Deep diffused Avalanche photodiodes for charged particles timing"* , M. Gallinaro et al., arXiv:1903.07482
- *"Search for Dark Matter produced in association with a Higgs boson in the four-lepton final state at 13 TeV"* , CMS collaboration, arXiv:1908.01713
- *"Measurement of B_s^0 meson production in pp and PbPb collisions at sqrt(s_{NN})=5.02 TeV"* , CMS Collaboration, Phys. Lett. B 796 (2019) 168
- ***"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, arXiv:1911.13204

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

- *"Search for rare decays of Z and Higgs bosons to J/Psi and a photon in proton-proton collisions at 13 TeV"* , CMS Collaboration, Eur. Phys. J. C 79 (2019) 94
- *"Search for tau -> 3 mu decays using tau leptons produced in D and B meson decays"* , CMS Collaboration, CMS-PAS-BPH-17-004
- *"Measurement of associated production of a W boson and a charm quark in proton-proton collisions at sqrt(s)=13 Tev"* , CMS Collaboration, Eur. Phys. J. C 79 (2019 269
- *"Observation of Two Excited B-c(+) States and Measurement of the B-c(+) (2S) Mass in pp Collisions at sqrt(s)=13 TeV"* , CMS Collaboration, Phys. Rev. Lett. 122 (2019 132001
- *"Observation of Single Top Quark Production in Association with a Z Boson in Proton-Proton Collisions at sqrt(s)=13 TeV"* , CMS Collaboration, Phys. Rev. Lett. 122 (2019 132003
- *"Multiparticle correlation studies in pPb collisions at 8.16 TeV"* , CMS Collaboration, Phys. Rev. C 101, 014912 (2020
- *"Measurement of the jet mass distribution in highly boosted top quark decays in pp collisions at sqrt(s)= 13 TeV"* , CMS Collaboration, https://cds.cern.ch/record/2682890
- *"Measurement of top quark pair production in association with a Z boson in proton-proton collisions at 13 TeV"* , CMS Collaboration, arXiv:1907.11270
- *"Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at root s(NN)=5.02 TeV"* , CMS Collaboration (2311 authors, Phys. Lett. B 797 (2019 UNSP 134826
- *"Measurements of correlations between J/Psi mesons and jets produced in root s = 8 TeV pp collisions"* , CMS Collaboration, CMS-PAS-BPH-15-003
- *"Measurement of the top quark polarization and tt spin correlations in dilepton final states at 13 TeV"* , CMS Collaboration, Phys. Rev. D 100, 072002 (2019)
- ***"Measurement of the top quark polarization and t(t)over-barspin correlations using dilepton final states in proton-proton collisions at root s=13 TeV"*** , CMS Collaboration, Phys. Rev. D 100 (2019) 072002
- ***"Higgs and Z decays to Jpsi Jpsi and Ypsilon Ypsilon",*** CMS Collaboration, Phys. Lett. B 797 (2019) 134811
- ***"Search for stops with taus in final state",*** CMS Collaboration, https://arxiv.org/abs/1910.12932
- ***"Search for stops with taus in final state" ,*** CMS Collaboration, https://arxiv.org/abs/1910.12932
- ***"Search for top squark pair production in a final state with two tau leptons in proton-proton collisions at 13 TeV",*** CMS Collaboration, https://arxiv.org/abs/1910.12932
- "Observation of the Lambda b to J/Psi Lambda Phi decay in proton-proton collisions at 13 TeV", CMS Collaboration, CMS-PAS-BPH-19-002
- "Nuclear modification factor of isolated photons in PbPb collisions at 5.02 TeV", CMS Collaboration, https://cds.cern.ch/record/2702011
- "Study of the B^+ to J/Psi Lambda p decay in proton-proton collisions at 8 TeV", CMS Collaboration, JHEP 12 (2019) 100
- "Search for low mass vector resonances decaying into quark-antiquark pairs in proton-proton collisions at sqrt(s)=13 Tev", CMS Collaboration, Phys. Rev. D 100 (2019) 112007

3 International Conference Proceedings

- *"Searches for Higgs bosons with dark matter at the Large Hadron Collider"*, M. Gallinaro (for the ATLAS and CMS Collaborations), PoS CHARGED2018 (2019) 024
- *"Flavor physics & beyond, a concluding review"*, N.Leonardo, JPCS 1137 (2019) 012060
- *"LUMIN: Lumin Unifies Many Improvements for Networks"*, G. Strong, https://github.com/GilesStrong/HiggsML_Lumin

3 Proposals, Yellow Reports and related studies

- ***"Higgs Physics at the HL-LHC and HE-LHC",*** M. Bengala, A. Costa, M. Fiolhais, M. Gallinaro, R. Gonçalo, A. Onofre, R. Santo, G. Strong et al.: CERN-LPCC-2018-04, arXiv:1902.00134
- ***"Report on the Physics at the HL-LHC and Perspectives for the HE-LHC",*** ATLAS and CMS Collaborations, CERN Yellow Reports: Monographs, [S.l.], v. 7, p. 1, dec. 2019. ISSN 2519-8076
- ***"Higgs boson potential at colliders: status and perspectives",*** M. Gallinaro et al., arXiv:1910.00012

10 Internal notes

- E.Melo, N.Leonardo, et al: "Searches for Z and Higgs boson decaying into Upsilon plus gamma in pp collision at 13 TeV with 2016 data", CMS AN-2018/032
- K. Shchelina, F. Nemes: "Optics and reconstruction formulae studies for PPS", CMS DN-2019-029
- *"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*
- *"Measurement of ttbar production xsection in the dilepton channel including a tau lepton at 13TeV using a profile likelihood fit", O. Toldayev, M. Gallinaro, P. Silva, J. Varela: CMS AN-2017/289*
- *"B meson production in PbPb data, signal extraction and MC validation", N.Leonardo, A.Pardal, J.Gonçalves, J.Silva: CMS AN-2019/219*
- *"Measurement of the polarization difference between the promptly produced χ_c1 and χ_c2 mesons in pp collisions at 8 TeV", Carlos Lourenço, Ilse Krätschmer, Thomas Madlener, Mariana Araújo, Pietro Faccioli, João Seixas, CMS AN-2019/045*
- *"Searching for exclusively produced top quark pairs", B. Ribeiro Lopes, P. Silva, M. Gallinaro, J. Hollar, CMS AN-2018/239*
- *"B^+ production in PbPb collisions at sqrt(sNN)= 5.02 TeV", N.Leonardo, J.Silva, et al, CMS AN-2019/132*
- *"A DNN-based classification approach for enhancing the search for Higgs boson pair production in the bbtautau final state in pp collisions at 13 TeV", M. Gallinaro, G. Strong, CMS AN-2019/188*
- *"Measurement of B_s meson production in PbPb collisions at sqrt(s_{NN})= 5.02 TeV", J.Silva, N.Leonardo, et al, CMS AN-2019/055*

1 Collaboration notes with internal referee

- *"Efficiency of the Si-strips sensors used in the Precision Proton Spectrometer: radiation damage"*, CMS Collaboration, CMS DP-2019/035

Presentations

6 Oral presentations in international conferences

- Nuno Leonardo: *"CMS Overview"*, 2019-01-16, COST Workshop on Higgs and Flavour Physics, IST, Lisbon
- Michele Gallinaro: *"Looking forward: Exclusive production with a leading proton"*, 2019-05-12, Workshop on "BSM models in Vector Boson Scattering processes", LIP, Lisbon
- Mariana Araújo: *"From identical S- and P-wave pT/M spectra to maximally distinct polarizations: probing NRQCD with LHC data"*, 2019-05-13, 13th International Workshop on Heavy Quarkonium, Torino, Italy
- Nuno Leonardo: *"Rare Decays (ATLAS, CMS, LHCb)"*, 2019-05-20, LHCP 2019 plenary talk, Puebla, Mexico

- Tahereh Niknejad: *"First experimental results on TOFHIR readout ASIC of the CMS Barrel Timing Layer"*, 2019-08-20, Topical Workshop on Electronics for Particle Physics (TWEPP), Santiago de Compostela, Spain
- Diogo de Bastos: *"Distributed Computing at the CMS Experiment: From the point of view of a physicis"*, 2019-09-25, IBERGRID 2019, Santiago de Compostela, Spain

7 Oral presentations in international meetings

- Giles Strong: *"hh->bbtautau at the HL-LHC YR studies"*, 2019-02-21, hh->bbtautau mini-workshop, LLR- Paris, France
- Pedrame Bargassa: *"Potential improvements of the ML based SM HTT analysis"*, 2019-03-13, Meeting with KIT team, Online
- Pedrame Bargassa: *"Potential improvements of the ML based SM HTT analysis"*, 2019-04-10, Meeting with KIT team, Online
- Giles Strong: *"LUMIN"*, 2019-04-17, 3rd IML Workshop, CERN, Switzerland
- Nuno Leonardo: *"CMS Highlights"*, 2019-04-26, IGFAE/LIP joint workshop, Santiago Compostela, Spain
- Giles Strong: *"Machine Learning in High Energy Physics"*, 2019-05-12, VBScan Workshop, LIP, Lisbon
- Giles Strong: *"Attempted reproduction of super-TML method"*, 2019-06-19, 3rd CMS ML Workshop, CERN, Switzerland

5 Poster presentations in national or international meetings

- Michele Gallinaro: ***"New physics searches at LHC: Looking forward and beyond",*** 2019-02-13, Fourth Lisbon mini-school on Particle and Astroparticle Physics, Caparica, Portugal
- Miguel Bengala: ***"CMS HL-LHC projections for non-resonant di-Higgs production in the bbtautau decay channel",*** 2019-02-27, Posters@LHCC, CERN, Switzerland
- Oleksii Toldaiev: ***"Measurement of ttbar quark pair cross-section with tau lepton in final state and lepton universality test",*** 2019-07-01, IDPASC workshop, Braga, Portugal
- Diogo de Bastos: ***"Search for the SUperSYmmetric partner of the top quark at the LHC with a multivariate approach",*** 2019-07-01, IDPASC/LIP PhD students workshop, Braga, Portugal
- Mariana Araújo: ***"Quarkonium production studies at LHC energies: towards the understanding of bound-state formation by the strong force",*** 2019-07-02, 5th IDPASC and LIP PhD Students Workshop, Braga, Portugal

13 Oral presentations in Advanced Training events

- Michele Gallinaro: ***"Top quark physics at the LHC",*** 2019-01-28, 7th ENHEP School on High Energy Physics, Cairo, Egypt
- Michele Gallinaro: ***"Top quarks: Probing the SM at the LHC",*** 2019-01-29, 7th ENHEP School on High Energy Physics, Cairo, Egypt
- João Varela: ***"Standard Model at the LHC",*** 2019-03-06, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"Top quark: Introduction",*** 2019-03-20, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"Top quark: Properties and beyond",*** 2019-03-25, Course on Physics at the LHC, LIP, Lisbon
- Giles Strong: ***"Keras Tutorial",*** 2019-03-26, LIP Data Science school 2019, Minho University, Portugal
- Pedrame Bargassa: *"Introduction to Supersymmetry I"*, 2019-04-18, Course on Physics at the LHC, LIP, Lisbon
- Pedrame Bargassa: *"Introduction to Supersymmetry II"*, 2019-04-23, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: *"Exotic processes and Dark Matter"*, 2019-05-06, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: *"Probing the SM at the LHC"*, 2019-07-16, Summer student program, LIP, Lisbon
- Giles Strong: *"Understanding Neural Networks"*, 2019-08-17, LIP Summer student tutorials, LIP
- Nuno Leonardo: *"Flavor Anomalies"*, 2019-10-05, LHC physics course (lecture), LIP, Lisbon

8 Seminars

- Pedrame Bargassa: *"Search for stop 4-body decays: Application of MVA tools & statistical methods to Susy search"*, 2019-02-06, Seminar for the KIT HEP group, KIT, Karlsruhe - Germany
- Michele Gallinaro: *"Highlights from the LHC: A personal perspective"*, 2019-03-09, Seminar, Cairo, Egypt
- Giles Strong: *"A dive into deep reinforcement learning"*, 2019-03-10, LIP seminars, LIP
- Nuno Leonardo: *"Highlights from the LHC"*, 2019-03-27, FCUL Physics Seminar, FCUL, Lisbon
- Michele Gallinaro: *"Higgs boson: Beyond the SM searches"*, 2019-04-15, Course on Physics at the LHC, LIP, Lisbon
- Nuno Leonardo: *"CMS highlights at the end of LHC Run2"*, 2019-07-03, LIP Seminar, LIP, Lisbon
- Nuno Leonardo: *"Rare Signals from Big Data"*, 2019-11-12, IST Physics Colloquium, IST, Lisbon
- Nuno Leonardo: *"A flavourful view from the LHC"*, 2019-11-21, UERJ Physics Colloquium, Rio de Janeiro, Brasil

7 Outreach seminars

- Diogo de Bastos: *"Partículas - do Universo ao laboratório"*, 2019-02-11, LIP's public session by LIP's students, LIP, Lisbon
- Beatriz Ribeiro Lopes: *"Heavy flavors, primordial medium, and rare higgs"*, 2019-02-27, ENEF 2019 -- LIP inside views, LIP, Lisbon
- Pedrame Bargassa: *"Hunting Supersymmetry & Higgs with the CMS detector"*, 2019-02-28, ENEF 2019, LIP, Lisbon
- Nuno Leonardo: *"Partículas!"*, 2019-03-23, Internacional MasterClasses particle physics, Universidade da Madeira, Funchal
- Diogo de Bastos: *"Masterclasses at IST"*, 2019-04-06, Masterclasses at IST, IST, Lisbon
- Giles Strong: *"PubHD talk: Machine learning in HEP"*, 2019-04-12, PubhD Lisboa, Lisbon
- José Carlos Silva: *"welcome to CERN , PTLTP2019"*, 2019-09-01, PTLTP2019, CERN

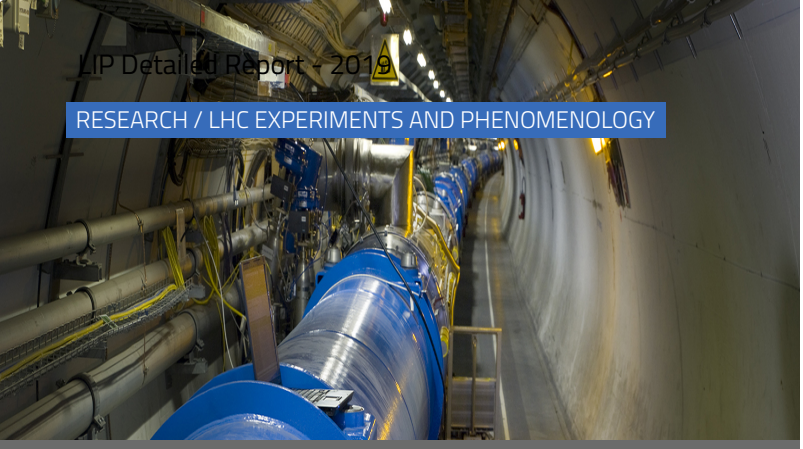
Theses

4 PhD

- Oleksii Toldaiev: *"Search for new physics processes with leptons in the final state at the Large Hadron Collider with the CMS detector"*, 2013-12-01 , (ongoing)
- Giles Strong: *"Search for double Higgs production new physics processes using Advanced Multi-Variate Analysis tools in the CMS experiment at the Large Hadron Collider"*, 2016-05-16 , (ongoing)
- 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)

2 Master

- Júlia Silva: *"Probing the quark gluon plasma medium through B meson production measurements in PbPb collisions at the LHC"*, 2018-09-01 / 2019-10-31, (finished)
- Beatriz Ribeiro Lopes: *"Study of the exclusive production of the top quark in the CMS experiment"*, 2018-10-07 / 2019-12-02, (finished)



PHENO

Phenomenology

Principal Investigator:
Guilherme Milhano (100)[+]

10 ***Researcher(s):***
António Onofre (30), Grigorios Chachamis (67), João Nuno Pires (19), Liliana Apolinário (85)[+], Miguel Fiolhais (35)[+], Miguel Romão (64), Nuno Castro (50)[+], Pietro Faccioli (50), Ricardo Gonçalo (20), Ruben Conceição (10)

4PhD Student(s):
Duarte Azevedo (20), Guilherme Guedes (100), Maria Ramos (90), Mariana Araújo (35)

7 ***Master Student(s):***
André Reigoto (50), Bruno Miguel Silva (100), Filipa Peres (100)[+], João Martins da Silva (12), João Pedro Gonçalves (100)[+], Pedro Lagarelhos (50), Rui Martins (50)

1 ***Undergraduate Student:***
João Moreira

4 ***Trainee(s):***
André Cordeiro, Iris Brée, Rafael Pinto, Sérgio Carrôlo

7 ***External collaborator(s):***
Artur Amorim de Sousa, Carlos Lourenço, João Lourenço Barata, Juan Antonio Aguilar Saavedra, Korinna Zapp, Pedro Martins Ferreira, Rui Santos

Total FTE:
12.4

Articles in international journals:
15 Direct contribution
International conferences:
10 Oral presentations
7 Proceedings
International meetings:
2 Oral presentations
Proposals, Reports and related studies:
3
Seminars:
4 Seminars
Completed theses:
3 Master

(+) Participation in the Competence Centre on Simulation and Big data within the project BigDataHEP included here

Executive summary

LIP's Phenomenology group conducts research bridging theory and experiment in particle and astro-particle 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.

The group was created in January 2018 following an extensive discussion process within LIP. In this second year of activity the group expanded its activities beyond the consolidated core (top-quark, Higgs, quarkonia, and heavy-ion phenomenology) into higher order QCD computations and their automation, and consolidated work on Dark Matter searches.

The members of the group have an excellent publication record and high international visibility. At the same time, its scientific output and appeal to students were strengthened.

This combination places the group on a positive path of continued 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
António Onofre	CERN/FIS-PAR/0034/2017	10.000 €	2018-01-01 / 2019-12-31	Phenomenological Studies at the 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 €	2020-03-01 / 2022-02-28	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: 792.562 €

Pheno

Lines of work and team organization

At present the group has internationally recognized consolidated research activities in top-quark, Higgs, quarkonia, precision QCD, and heavy-ion phenomenology with a strong expertise in the development of event-generators. Phenomenological activities on Dark Matter searches, previously conducted within but independently of LIP's experimental groups, have affirmed themselves within the group. The close connection between work on simulation of cosmic ray air showers carried out in others groups and our QCD activities is being 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, on-going discussions are leading to the identification of topical issues where complementary expertise within the group can lead to international leadership in new domains.

Stated objectives for past year

A first key objective for 2019 was too extend the scope of the group's activities to include higher order computations in QCD and forward physics potentiating improved links within the group and with the Cosmic Rays and LHC experimental groups.
Second, the group aimed to explore synergies with the Simulation and Big Data competence centre through the development of Machine Learning joint projects in heavy-ion jet studies and discrimination of production modes for vector-like quarks.
Third, the group intended to continue to attract students and researchers following a strategy of sustained growth.
Finally, the group aimed to obtain essential funding for structural support.

Achievements and responsibilities during the past year

- In 2019 it was possible, with two new researchers, to successfully expand the research scope of the group to higher order QCD computations including their automation, and forward physics. Work on Dark Matter Searches, in the context of extensions of the Standard Model, has been consolidated with two doctoral students. First publications in these domains pave a promising future path.
  The exploration of synergies with the Simulation and Big Data competence centre resulted in two projects: one, submitted for publication, on the Transferability of Deep Learning Models in Searches for New Physics at Colliders; and another, on-going, on the distinction between jets modified by their propagation in a QGP and their vacuum counterparts using image processing techniques.
  The international high visibility of the group was confirmed by several invitations for seminars and conference talks, notably at Quark Matter where for the third consecutive edition a different member of the group delivered a plenary talk.
  The group was responsible for the supervision of three MSc theses successfully defended in 2019. Two of the these were carried out in collaboration with the Simulation and Big Data competence centre, one of which in a Minho-Lisbon co-supervision.
  Among our excellent publication output we highlight:

- a proposal [PRL 122, 222301] for model-independent determination of the average transverse momentum lost by jets in the QGP applicable to dijet events where the initial transverse momentum of the parton that initiates a jet is not experimentally accessible;

- the calculation [PRL 123, 102001] to NNLO of the Triple Differential Dijet Cross Section at LHC energies;

- the observation [EPJC79, 457] that measured quarkonia differential cross section shapes, when expressed in terms of dimensionless kinematic variables, become identical for all S- and P-wave charm and bottom quarkonia leading to a conceptual challenge to NRQCD and pointing towards either a violation of the base scaling hierarchies or a full degeneracy of the assumed factorized expansion of the production cross sections;

- the identification [PRD100, 115015] of novel B-decay signatures of light scalars measurable at high energy facilities;

- publication of the FCC proposal and report on high luminosity opportunities with heavy-ion collisions, where the group had a strong participation.

The group secured funding from national and european competitive calls, including its first grant for structural support.

Lines of work and objectives for next year

In 2020 the group expects to continue to deliver high impact research across its lines of work. The much improved funding situation will allow for the hiring of a number of postdoctoral researchers which we expect will contribute to a significant increase in output.

Following the successful integration of precision QCD research into the group portofolio, we will conduct an internal reflection exercise to identify future areas of expansion and develop a realistic implementation strategy. We expect activities on BSM to fully become consolidated in the group.

Work within consolidated areas - top-quark, Higgs, quarkonia, precision QCD, and heavy-ion phenomenology - is expected to have a strong focus on data-driven/model-independent studies. Studies targeted at harnessing the full potential of the next phases of the LHC will be a priority across our research universe. In particular in what regards the need for theoretical precision matching experimental uncertainties from high-luminosity runs and the high potential of collisions of ligther-than-Lead ions to elucidate the mechanisms of emergence of complexity from the simple fundamental laws of QCD.

The already strong synergy with the Simulation and Big Data competence centre will be further developed as, increasingly, Machine and Deep Learning techniques become ubiquitous in our work. Synergies with the Cosmic Ray experimental groups and the Nuclear Physics and Strong Interaction group that recently joined LIP will be identified in view of future closer collaboration.

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 broaden its research scope into areas of strategic and topical importance. This includes precision collider phenomenology and related BSM searches. Inevitably, this also implies an increase in the number of members of the group and, significantly, an increase in the number of researchers in full-time dedication.

To be internationally relevant and recognised during the high-luminosity phase of the LHC, the group expects to be capable of playing a leading role in interpreting data and proposing innovative analyses.

In the medium term, therefore, the group's identity would be further consolidated to serve 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.

Pheno

Publications

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

- *"Gravitational wave and collider probes of extended Higgs sectors with a low cutoff"*, Mikael Chala (Durham U., IPPP), Maria Ramos (LIP, Minho), Michael Spannowsky (Durham U., IPPP), Eur. Phys. J. C (2019) 79: 156
- *"Models with extended Higgs sectors at future e(+)e(-) colliders"*, Duarte Azevedo, Pedro Ferreira, M. Margarete Muehlleitner, Rui Santos, Jonas Wittbrodt, Phys. Rev. D 99 (2019) 055013
- *"Simultaneous description of hadron and jet suppression in heavy-ion collisions "*, J. Casalderrey-Solana, Z. Hulcher, G. Milhano, D. Pablos, K. Rajagopal, Phys.Rev. C99 (2019) no.5, 051901
- *"NRQCD colour-octet expansion vs. LHC quarkonium production: signs of a hierarchy puzzle?"*, Pietro Faccioli, Carlos Lourenco, Eur. Phys. J. C 79 (2019) 457
- *"Sorting out quenched jets"*, J. Brewer, J. G. Milhano, J. Thaler, Phys.Rev.Lett. 122 (2019) no.22, 222301
- *"FCC Physics Opportunities : Future Circular Collider Conceptual Design Report Volume 1"*, FCC Collaboration, Eur.Phys. J. C79 (2019) no.6, 474
- *"Top quark anomalous couplings at the high-luminosity phase of the LHC"*, Frederic Deliot, Miguel C. N. Fiolhais, Antonio Onofre, Mod. Phys. Lett. A 34 (2019) 1950142
- *"Differential Dijet Cross Section at the LHC"*, Aude Gehrmann-De Ridder, Thomas Gehrmann, E.W.N. Glover, Alexander Huss, Joao Pires, Phys. Rev. Lett. 123, 102001 (2019)
- *"Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum"*, D. Abercrombie et al., Phys. Dark Univ. 27 (2020) 100371
- *"Calculations for deep inelastic scattering using fast interpolation grid techniques at NNLO in QCD and the extraction of alpha_s from HERA data"*, D. Britzger, J. Currie, A. Gehrmann-De Ridder, T. Gehrmann, E.W.N. Glover, C. Gwenlan, A. Huss, T. Morgan, J. Niehues, J. Pires, K. Rabbertz, M.R. Sutton, Eur.Phys.J. C79 (2019) no.10, 845
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- *"Novel B-decay signatures of light scalars at high energy facilities"*, Andrew Blance, Mikael Chala, Maria Ramos, Michael Spannowsky, Phys. Rev. D 100 (2019) 115015
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- *"Modi cation 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

7 International Conference Proceedings
- *"A simultaneous understanding of jet and hadron suppression"*, J. Casalderrey-Solana, Z. Hulcher, G.Milhano, D. Pablos, K. Rajagopal, Nucl.Phys. A982 (2019) 575-578
- *"Unveiling the yoctosecond structure of the QGP with top quarks"*, Liliana Apolinário, Guilherme Milhano, Carlos A. Salgado, Gavin P. Salam, Nucl.Phys. A982 (2019) 795-798
- *"Overview of jet quenching and energy loss in heavy-ion collisions "*, Liliana Apolinário, PoS LHCP2018 (2018) 219
- *"Thoughts on opportunities in high-energy nuclear collisions "*, F. Antinori et al., e-Print: arXiv:1903.04289
- *"Jets in QCD matter: Monte Carlo approaches"*, Liliana Apolinário, PoS HardProbes2018 (2019) 022
- *"alpha_s (2019): Precision measurements of the QCD coupling"*, David d'Enterria, Stefan Kluth (eds.), S. Alekhin, et.al., PoS ALPHAS2019 (2019)
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3 Proposals, Yellow Reports and related studies
- FCC Collaboration: "FCC-ee: The Lepton Collider: Future Circular Collider Conceptual Design Report Volume 2", Eur. Phys. J.-Spec. Top. 228 (2019) 261-623
- FCC Collaboration: ***"FCC-hh: The Hadron Collider: Future Circular Collider Conceptual Design Report Volume 3",*** Eur. Phys. J.-Spec. Top. 228 (2019) 755-1107
- the FCC Collaboration: ***"HE-LHC: The High-Energy Large Hadron Collider Future Circular Collider Conceptual Design Report Volume 4",*** Eur. Phys. J.-Spec. Top. 228 (2019) 1109-13820.00012

Presentations

10 Oral presentations in international conferences
- Maria Ramos: *"Gravitational wave and collider probes of extended Higgs sectors with a low cutoff"*, 2019-01-14, COST

  Workshop on Higgs and Flavour Physics: Present and Future, Lisboa
- Guilherme Milhano: *"Prospects with light ions in Run 5 and heavy ions at HE-LHC"*, 2019-03-01, HL/HE-LHC Physics Workshop: final jamboree, CERN, Switzerland
- Maria Ramos: *"Scalar composite dark matter in non-minimal models"*, 2019-04-08, Dark Matter Identification: Connecting Theory and Signature Space, Mainz Institute for Theoretical Physics, Johannes Gutenberg University
- Maria Ramos: *"Scalar composite dark matter in non-minimal models"*, 2019-04-08, Dark Matter Identification: Connecting Theory and Signature Space, Mainz, Germany
- Mariana Araújo: *"From identical S- and P-wave pT/M spectra to maximally distinct polarizations: probing NRQCD with LHC data"*, 2019-05-16, 13th International Workshop on Heavy Quarkonium, Torino, Italy
- Liliana Apolinário: *" Time evolution of a medium-modified jet"*, 2019-07-10, EPS-HEP 2019, Ghent, Belgium
- João Nuno Pires: *"NNLO QCD predictions for the LHC with antenna subtraction"*, 2019-11-04, WorkStop/ThinkStart 3.0: paving the way to alternative NNLO strategies Florence, Florence, Italy
- Liliana Apolinário: *" Road map to extracting medium properties: an overview (Plenary)"*, 2019-11-07, Quark Matter 2019, Wuhan, China
- Maria Ramos: *"Gravitational waves and collider probes of extended Higgs sectors"*, 2019-11-13, Gravitational Wave Probes of Fundamental Physics, Amsterdam, Netherlands
- João Nuno Pires: *"Jets Theory Overview"*, 2019-11-28, 15th Vienna Central European Seminar on Particle Physics and Quantum Field Theory, Vienna, Austria

2 Oral presentations in international meetings

- Liliana Apolinário: *" Physics with heavy ions at FCC"*, 2019-03-05, Physics at FCC: overview of the Conceptual Design Report, CERN, Switzerland
- João Nuno Pires: *"Current theory status for jet production at the LHC"*, 2019-04-23, QCD@LHC2019, Zurich, Switzerland

4 Seminars

- Guilherme Milhano: *"Jets as probes of Quark Gluon Plasma"*, 2019-01-09, Milano, Italy
- Maria Ramos: *"Complementarity between gravitational waves and colliders in a triplet Higgs sector"*, 2019-03-08, IPPP seminar, Durham, United Kingdom
- Maria Ramos: *"Complementarity between gravitational waves and collider probes in extended Higgs sectors"*, 2019-05-15, Gr@v seminar,
- Pietro Faccioli: *"Dilepton polarization: invariants, the Lam-Tung relation and beyond"*, 2019-06-07, COMPASS seminar, CERN, Switzerland

Theses

3 PhD

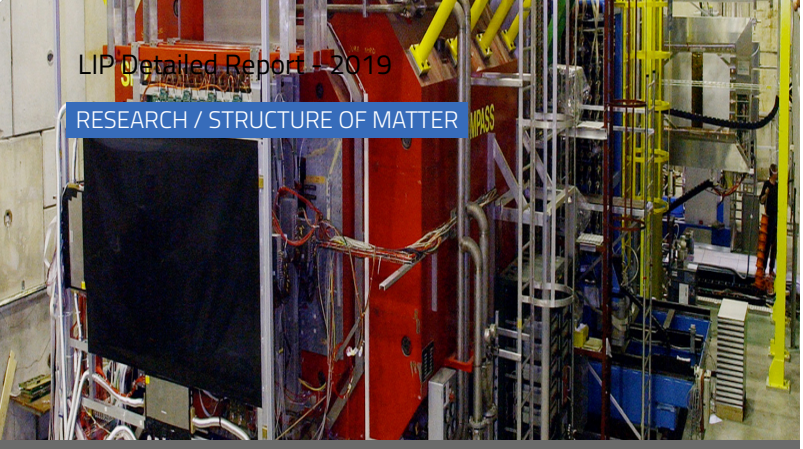
- Maria Ramos: *"Interplay between collider and astrophysical signals of non-minimal composite Higgs models"*, 2017-11-15 , (ongoing)
- Guilherme Guedes: *"Collider and astrophysical constraints to little Higgs models"*, 2018-11-13, (ongoing)
- Mariana Araújo: *"Quarkonium production studies at LHC energies: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

4 Master

- Bruno Miguel Silva: *"Searching for jet quenching in small systems"*, 2018-11-01 / 2019-11-29, (finished)
- João Pedro Gonçalves: *"Topic modelling for jets"*, 2018-11-01 / 2019-11-29, (finished)
- Filipa Peres: *"New observables and techniques for the study of jets in hadron collisions"*, 2018-09-15 / 2019-12-12, (finished)
- João Martins da Silva: *"Application of Machine Learning Techniques to heavy-ion jets"*, 2019-11-20, (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)

5 ***Researcher(s):***
Celso Franco (65), Marcin Stolarski (80), Márcia Quaresma (65), Pietro Faccioli (26), Sofia Nunes (8)

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

1 ***Undergraduate Student:***
Rita Silva

2 ***Trainee(s):***
Michelangelo Lixi, Michele Filippucci

Total FTE:
4.5

Articles in international journals:
2 Direct contributions
1 Indirect contribution
International conferences:
2 Oral presentations
1 Proceeding
International meetings:
1 Oral presentation
Collaboration meetings:
8 Oral presentations
Seminars:
2 Seminars
Organized events:
1 Collaboration meeting
1 International Conference or Workshop

Executive summary

COMPASS is a fixed target experiment at CERN, using high energy muon and hadron beams to study the nucleon spin structure and hadron spectroscopy. During its first phase COMPASS achieved the world' s most direct and precise measurement of the gluon contribution to the nucleon spin. A second research programme started in 2012 and is now close to completion, devoted to the 3-dimensional characterization of the nucleon structure. An addendum to the COMPASS-II proposal was approved in 2018 by the CERN Research Board, for additional deep inelastic scattering (DIS) measurements using a transversely polarised deuteron target in 2021. This unique measurement shall lead to an accurate determination of the spin-dependent transversity distribution of the d-quark in the nucleon, and extraction of the corresponding tensor-charge.

The LIP-Lisbon group joined COMPASS in 2003 and since then it has been involved in the main analyses of the Collaboration. The group has sole responsibility for the Detector Control System, an area where it has a recognized unique expertise. The LIP group is also strongly involved in the preparation of a new CERN experiment, AMBER, using the same beam line and parts of the COMPASS spectrometer, to address important QCD-related topics. A Letter of Intent was produced in January 2019, and a Scientific Proposal in May 2019.

The 2018 data-taking of COMPASS was devoted to the study of the pion-induced Drell-Yan process on a transversely polarised proton target. The analysis of the COMPASS 2015 data, taken in similar conditions, gave a first hint to the importance of parton transverse momentum dependent effects to the nucleon dynamics. The 2018 collected sample is now being analysed, with direct contribution from the Lisbon team. It is expected to significantly improve the statistical significance of the observed signals.

The unpolarised semi-inclusive DIS data collected by COMPASS in 2016 and 2017 are being analysed by members of the LIP team. Charged hadron multiplicity studies, namely on identified kaons and protons, are an important ingredient for fragmentation functions extraction. COMPASS results have evidenced, for the time, discrepancies with respect to the perturbative QCD theory expectations.

Sources of funding

PI	Code	Amount	Dates	Description
Catarina Quintans	CERN/FIS-PAR/0007/2017	144.500 €	2017-09-01 / 2019-08-31	Collaboration in the COMPASS experiment at CERN
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: 299.500 €

Partons and QCD

Lines of work and team organization

The work developed by the LIP group is organized in four main tasks: Detector Control System (DCS); Deep inelastic scattering (DIS) studies; Drell-Yan studies; and studies for the new AMBER project.

The DCS team is responsible for the development and implementation of controls and monitoring for all COMPASS detectors. The system is kept up-to-date and permanently running, including during the shutdown periods. The group provides the on-call service both for Physics Runs and Dry Runs (case of 2019/2020). The team is lead by Christophe Pires with support from Catarina Quintans.

The DIS data collected in 2016 and 2017 using muon beams is being studied by Marcin Stolarski. Pion and kaon multiplicities previously published by COMPASS from an isoscalar 6LiD target, are now being complemented by an analysis of proton/antiproton multiplicities. The multiplicities at high z (fraction of energy of the virtual photon carried by the hadron), which have shown a clear discrepancy with the pQCD predictions, are a subject of dedicated studies. The new analysis will benefit from recent RICH particle identification improvements in extended momentum range.

The Drell-Yan data collected in 2015 and 2018 is being analysed. The 2015 data was reprocessed to include reconstruction improvements, while the 2018 data had a first test production in 2019, and very preliminary results on part of the statistics were already released. Márcia Quaresma, who re-joined the LIP team in September 2019 (after 2 years of a postdoctoral fellowship in Taiwan), is one of the main analysers for the transverse spin dependent azimuthal asymmetries. Celso Franco proceeds studies on the use of deep neural network methods for separating Drell-Yan and charmonium signals from background. Pietro Faccioli dedicates to the J/psi unpolarized azimuthal asymmetries analysis, namely by advising on systematics related studies. Catarina Quintans coordinates the COMPASS Drell-Yan group.

The LIP team is deeply involved in the preparation of the AMBER new experiment. Catarina Quintans, Márcia Quaresma and Pietro Faccioli participate in the drafting of the Scientific Proposal and discussions with SPSC referees. Márcia Quaresma coordinates the AMBER group for Drell-Yan studies.

Stated objectives for past year

As objectives for 2019, the LIP COMPASS group pointed to the following:

- Direct contribution in the ongoing Drell-Yan analyses, namely in the aspects of global coordination; differential Drell-Yan cross-section measurement; and neural network methods for signal from background separation.
- Direct contribution in the identified hadron multiplicity measurement from SIDIS data, namely with the analysis of 2016 and 2017 collected data.
- Upgrade of the DCS of COMPASS, preparing it for the 2021 data-taking period.
- Co-organization of the "XVI International Workshop on Hadron Structure and Spectroscopy - IWHSS 2019", together with the Aveiro University and I3N group in COMPASS.

Achievements and responsibilities during the past year

The 2018 Drell-Yan (DY) Run was quite successful, providing a sample 1.5 times larger than the one from 2015. Fast data processing happened in the first months of 2019, and the physics analysis progressed in record time. The preliminary results on the DY transverse spin asymmetries (TSAs) were made public by Spring 2019. These asymmetries are convolutions of transverse momentum dependent parton distribution functions (TMD PDFs), which are also accessed through the SIDIS process measured in COMPASS. The complementarity of these two processes is explored in COMPASS, the only experiment able to access both, with the same polarised target and experimental apparatus. An advantageous cancellation of part of the systematic errors occurs in the TSAs analysis, reason why these were the first results to be obtained.

Several team members are experienced and deeply involved in the Monte-Carlo (MC) simulations. A multivariate analysis that separates competing processes from the DY is lead by a member of the LIP team. The TSAs analysis uses dimuons with invariant mass greater than 4.3 GeV/c^2. According to MC studies, this mass cut guarantees a DY purity above 96%. However, the LIP group already demonstrated the feasibility of decreasing this lower mass limit to 4.0 GeV/c^2, with consequent increase in the sample size by 30%, while keeping the level of background contamination at the same level as before.

The DIS data collected by COMPASS, using muon beams of both charges, is studied by the LIP group, aiming at the extraction of the so-called fragmentation functions (FFs) from the hadron multiplicities. The COMPASS published pion and kaon multiplicities, measured in a wide kinematical range on an isoscalar 6LiD target, are a crucial input for any global analysis of FFs. To better understand the quark fragmentation process several items need to be studied further. Recent RICH particle identi cation improvements pursued by team members provide a gain in statistics, and enlarge the accessible momentum range, by 40%. The antiproton to proton multiplicity ratio was recently analysed and found to disagree with the perturbative QCD expectation, as was already found in the kaons case.

A new project, the AMBER experiment at the M2 beam line of the CERN SPS, was rst proposed by COMPASS members, to whom many other international groups joined. A novel scienti c program to study fundamental QCD-related topics was submitted in the form of a Letter of Intent in January 2019.
A Proposal for a first phase of AMBER measurements followed in May 2019, and started being evaluated by the SPS Committee of CERN in November 2019. The LIP group is one of the proponents and main authors of this Proposal, being deeply involved in its drafting and discussion with SPSC referees.

The recent COMPASS results, advances in the theory, and the physics case for AMBER, were among the topics addressed at the XVI International Workshop on Hadron Structure and Spectroscopy, co-organized by the LIP-Lisbon group, together with the Aveiro/I3N group. The workshop took place in the Aveiro University, from 24 to 28 June 2019, and counted 85 participants.

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 LIP group plans to directly contribute in the ongoing analyses, namely in the aspects of: coordination, co-supervision, and analysis. The COMPASS physics subgroup is coordinated by Catarina Quintans who closely follows all the DY and charmonium physics analyses. One of the main goals for 2020 is the release of DY differential cross-sections, with an expected signi cant impact in the pion PDF extractions and the study of cold nuclear matter effects. Meanwhile, the analysis of the full 2018 data set by Márcia Quaresma (among others) shall continue, once the data re-processing is completed. Pietro Faccioli, who has recognised expertise in quarkonium studies, joined the group in 2019 with a speci c interest in the J/psi polarization both in COMPASS and AMBER, an analysis done by Taiwanese students that presently bene ts from his advise. Celso Franco continues the development of a new method of signal from background separation based on deep neural networks, now in collaboration with an American student.

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). In these years, the COMPASS setup included a recoil proton detector and an upgraded RICH detector, which are essential for multiplicity studies. Large impact is expected from these data sets, collected on a liquid hydrogen target. These data are much easier to analyse from the theoretical point of view than those previously studied, that used a 6LiD target. COMPASS is presently the only DIS experiment in the world with a beam energy above 20 GeV, thus it is a world unique facility to perform this kind of measurement. The LIP team leads the COMPASS studies of charged kaon, pion and proton multiplicity ratios at high fraction of the virtual photon energy carried by the hadron, in order to better understand quark fragmentation in this region. A new publication on the antiproton to proton multiplicity ratio from 2006 data is expected during 2020, with Marcin Stolarski as corresponding author.

Taking the opportunity of the 2019/2020 long shutdown period at CERN (LS2), the DCS of COMPASS is being upgraded, to prepare it for the 2021 data-taking period. The implementation of new supervision solutions, eventually useful for AMBER and other future xed target experiments, is being tested, in line with the most up-to-date solutions proposed at CERN. The DCS activities are coordinated by Christophe Pires, the main developer. The group is in close contact and cooperates with the CERN Industrial Controls group. The team is also relying on the continued COMPASS Collaboration support to these activities.

The proponents of the new AMBER project have submitted a first Scientific Proposal in 2019. The document is presently being discussed with the designated SPS Committee referees. An eventual approval by the CERN Research Council is expected during 2020. Márcia Quaresma is presently the AMBER coordinator for Drell-Yan and charmonium studies. Pietro Faccioli is the main promoter for a comprehensive study of charmonium production mechanisms at the intermediate energies of AMBER. Catarina Quintans is one of the co-organizers of an International Workshop “Perceiving the Emergence of Hadron Mass through AMBER at CERN”, to take place at CERN from 30 March to 3 April 2020. The Lisbon group is involved in the feasibility studies for the AMBER DY and charmonium measurements, namely in the aspects of environmental radiation simulations and optimisation of shielding; and concept of a new vertex detector for DY measurements and its inclusion in the data reconstruction software. This latter topic is done in close cooperation with the group from the Aveiro University, with recognised expertise in the field of detectors and instrumentation.

Medium-term (3-5 years) prospects

The plans of the group for the coming years can be summarized as follows:

- Proceed the ongoing physics analyses which are the responsibility of group members;
- Upgrade the Detector Control System (DCS) of COMPASS for the 2021 Run and beyond;
- Participate in the studies for the AMBER project.

The present scientific programme of COMPASS will be completed with the 2021 data taking, but the analyses will certainly extend for 3 to 5 years after that. Meanwhile, a new experiment is being proposed, AMBER, addressing a wide range of QCD-related topics: proton charge radius measurement from high energy muon-proton elastic scattering; pion and kaon distribution functions and their connection to the emergence of hadron mass in QCD, via the meson-induced Drell-Yan process; a vast program on kaon spectroscopy; among others. This physics program naturally follows the COMPASS one, but extending much beyond thanks to the progress in the field in the past years.

New methods of analysis are being explored, using machine learning techniques and deep neural networks to classify events as signal or background, and also for pattern recognition in the RICH detector. The potential of this kind of approach is increasingly explored in the HEP field. In COMPASS, M. Stolarski and C. Franco are presently the researchers with most expertise in this. The group plans to invest further efforts in this field in the future.
The group know-how in the DCS has been consolidated over the years, in dialogue with CERN Controls groups. While adapting the system to the newest standards during the LS2 break, the group is also considering new developments, possibly useful also for other experiments, which are jointly being discussed.

SWOT analysis

The LIP group is fully integrated in COMPASS, both in the technical and in the physics analyses aspects. It is also deeply involved in the preparation of the future AMBER experiment. The acquired expertise in the DCS and the excellent reliability of the system are well recognised by the Collaboration and also by CERN. Leading roles in coordination of physics analyses and in the drafting of papers and proposals are taken by team members. The team is motivated and the knowledge within the group opens new possibilities for the future.

The LIP group cooperates with the Aveiro University and I3N group in COMPASS, a group with competences in the Instrumentation area. In the field of controls and automation, the LIP group has been in close contact with the CERN Industrial Controls group for the test of new solutions during the Long Shutdown period at CERN.

In the context of the Erasmus+ European project, undergraduate students from Turin make internships integrated in the LIP group, since 2018. The group also participates in the LIP Summer Internships Programme.

The LIP group was reduced in terms of members in recent years, but the responsibilities taken in COMPASS and in AMBER are to be continued. In spite of the strong effort done in Outreach, the team was not able to attract new master or PhD students to the project, up to now. For the latter, this was due to lack of grant possibilities. Concerning masters opportunities, since no member of the group is presently teaching in the University, we try to propose theses topics in association with other colleagues working in similar elds.

The group grew in 2019, with the entrance of Pietro Faccioli and Márcia Quaresma. On the other hand, Ana Sofia Nunes left the group in February 2019, after being selected for a competitive international postdoctoral fellowship in the Brookhaven National Laboratory.

The nancing obtained via the 2019-2021 CERN Fund is not enough to pay for more than 12 months of a research contract, thus the project funded position (M. Quaresma), essential for the completion of the scienti c goals of the group, is a serious concern.

At the moment, the delay on the AMBER experiment approval is seen as a weakness when applying to grants or other funding.

Partons and QCD

Publications

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

- *"Measurement of PT-weighted Sivers asymmetries in leptoproduction of hadrons"*, COMPASS Collaboration, Nucl. Phys. B 940 (2019) 34–53
- *"Transverse extension of partons in the proton probed in the sea-quark range by measuring the DVCS cross section"*, COMPASS Collaboration, Phys.Lett.B 793 (2019) 188-194

1 International Conference Proceedings

- *"High-z proton and kaon multiplicity ratios on deuteron target in SIDIS"*, M. Stolarski on behalf of COMPASS Coll., PoS DIS2019 (2019) 207

Presentations

2 Oral presentations in international conferences

- Marcin Stolarski: *"High-z proton and kaon multiplicity ratios on deuteron target"*, 2019-04-06, XXVII International Workshop on Deep Inelastic Scattering (DIS 2019), Torino, Italy
- Celso Franco: *"Hadron structure results from COMPASS and plans for AMBER"*, 2019-09-24, 15th Rencontres du Vietnam - Perspectives in Hadron Physics, Quy Nhon, Vietnam

1 Oral presentations in international meetings

- Catarina Quintans: *"COMPASS++/AMBER: A New QCD Facility at the M2 beam line of the CERN SPS"*, 2019-12-11, meeting of the Theory initiative , CERN

2 Seminars

- Catarina Quintans: *"AMBER: unravelling QCD mysteries"*, 2019-02-21, LIP Seminar, LIP - Lisboa
- Márcia Quaresma: *"The light sea quarks asymmetry in proton from the SeaQuest experiment at Fermilab"*, 2019-10-17, LIP Seminar, LIP - Lisboa

Organized Events

1 Collaboration Meetings

- *"COMPASS Collaboration Meeting"*, [Coll-Mtg] 2019-06-27 / 2019-06-28, Universiade de Aveiro, Aveiro, Portugal

1 International Conferences or Workshops

- IWHSS 2019 - Int. Workshop on Hadron Structure and Spectroscopy, Universidade de Aveiro, Aveiro, Portugal, 2019-06-24 to 2019-06-26

HADES

Collaboration in the HADES experiment at GSI

Principal Investigator:
Alberto Blanco (15)

2 ***Researcher(s):***
Celso Franco (5), Paulo Fonte (5)

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

Total FTE:
0.5

Articles in international journals:
1 Direct contribution
8 Indirect contribution
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-COMPAS 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.

The accelerator infrastructure at GSI was shutdown during the last years to be upgraded, with the aobjetive of putting into operation the future SIS100 synchrotron at the new FAIR facility, providing higher beam energies and intensities. The upgraded HADES spectrometer, with a new (although incomplete) electromagnetic calorimeter (ECAL) and a new RICH detector, has already successfully accomplished a production run with Ag+Ag collisions at 1.58 AGeV in March 2019. HADES will be one of the first experiments to be operational at FAIR with the mission of providing high-quality dilepton data at baryon densities and temperatures not accessible by other detectors, neither in the past nor in the foreseeable future.

The group activities are financially supported only by a modest quantity in the framework of a MoU. Any opportunity of funding is pursued. In the last years a new project has been submitted to the national PTDC call together with a strong group from IST Lisbon (which has recently joined LIP), whose theoretical work is of special interest for HADES. The project was not recommend for funding. In 2020, there will be a new opportunity within PTDC call (already open).

Sources of funding

PI	Code	Amount	Dates	Description
Alberto Blanco	000-HADES	10.000 €		HADES generic funding

Total: 10.000 €

HADES

Lines of work and team organization

As mentioned, after the leave of the people involved in data analysis only the line related with hardware is still active, which 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 detector, Forward Detector (FD), is composed by a tracking detector and a TOF detector. The LIP group is in charge of the simulation, design and construction of the TOF detector of the FD, RPC-TOF-FD. Responsibility: A. Blanco, P. Fonte, L. Lopes and J. Saraiva.
- **Preparing the HADES Tracking System for High-Rate Experiments at SIS100.** The future physics program of HADES at FAIR demands high detection standards and stability of the tracking system due to the expected increase of the beam energies and intensities. The LIP-HADES group collaborates in this task with the MDC group. Responsibility: L. Lopes.

Stated objectives for past year

- Participate in the data taking with Ag+Ag at 1.58 AGeV.
- Finalize the implementation of the RPC-TOF-FD in the official software of the experiment.
- Finalize the construction of the four modules of the RPC-TOF-FD and the mechanical structure that hold them and subsequent installation and commissioning in the HADES cave.
- Together with the MDC group the postponed rebuilt of plane II will be accomplished. Together with plane III. Upgrade and recalibration of the gas system. Continuation of the tests with Lenav2 ,which include also the front end electronics (FEE) upgrade. Integration of the new FEE in the HADES main CAD, to check for possible constrains. Monitoring chambers performance during Ag+Ag data taking.
- Start the analysis of the dilepton data that HADES will collect during 2019 using Ag+Ag at 1.58 AGeV.

Achievements and responsibilities during the past year

Participation, as RPC, MDC and DAQ operators and shift leader, in the Ag+Ag at 1.58 GeVs data taking in March 2019 and the subsequent disassembly of three RPC sectors to allow the completion of the implementation of the ECAL detector.

With the aim of achieving an acquisition rate of more than 200 kHz, the HADES data acquisition system is in continuous development. For this reason the acquisition boards of the RPC-TOF-W will be upgraded from the version TRB2 to TRB3sc. This system was installed in one of the sectors at the end of the year for validation.

In the middle of 2019, it was verified that the design proposed for the RPC-TOF-FD was not valid. This is mainly due to the readout implemented in the proposed detector, which is not compatible with the rate and multiplicity to which the RPC-TOF-FD will be exposed. This design error was not detected previously due to the lack of manpower that caused a systematic delay in the simulation of the detector. At this point all work on this design stopped and a new design, based on individually shielded RPCs (the same technology used in the RPC-TOF-W) was proposed for the RPC-TOF-FD. A prototype composed of six individually shielded RPCs was tested with 2.2 GeV/c protons at the end of 2019. The prototype was able to provide a detection efficiency above 90% together with a timing accuracy below 100 ps (design requirements together with a maximum rate capability of 320 Hz/cm²) with particle fluxes of around 250 Hz/cm² at room temperature. However, taking profit of the decrease of the glass resistivity by increasing the operational temperature of the detector and the corresponding increase of rate capability, similar results were obtained at 40ºC with particle fluxes of around 500 Hz/cm² reaching around 1 kHz/cm² with a modest drop on the detection efficiency down to 89%. These results validate the individually shielded RPCs to be used in the HADES TOF FD. Consequently, the construction of the first module (out of a total of four) started at the end of 2019.

One of the MDC chambers, form the tracking system, was repaired (as planned) and one was also repaired in an emergency (not planned) as the system was essential for the March data taking. The new electronics of the tracking system was included in the CAD of the prototype lenav2 (which explore new configurations for the future upgrade of the tracking system) and this was tested in beam at the end of the year with promising results.

All the tasks related to the analysis, after the leave of the people involved in data analysis, were not performed.

Lines of work and objectives for next year

- 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.

Medium-term (3-5 years) prospects

Currently the group dedicates about 0.50 FTE to the HADES activities, but it should be taken into account that part of the work is supported by the RPC R&D group together with LIP infrastructures (Detector Laboratory and Mechanical Workshop). As already mentioned, the group at this time, is limited to activities related to the development of RPCs and MDCs. We do not exclude the possibility of incorporating activities related to data analysis again in the future, but this is not a priority at this time. The medium term prospect for the next years is focused in our main three lines:

- Optimize (in particular finalize the DAQ upgrade during 2019), prepare and operate for production beam times the RPC-TOF-W.
- Finalize the construction, commissioning and integration of the new RPC-TOF-FD in 2019 and 2020.
- 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.

During 2020 there will be a new opportunity of funding in Portugal (PTDC2020) to which we will apply together with the rest of the activities related to FAIR that exist at LIP.

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.

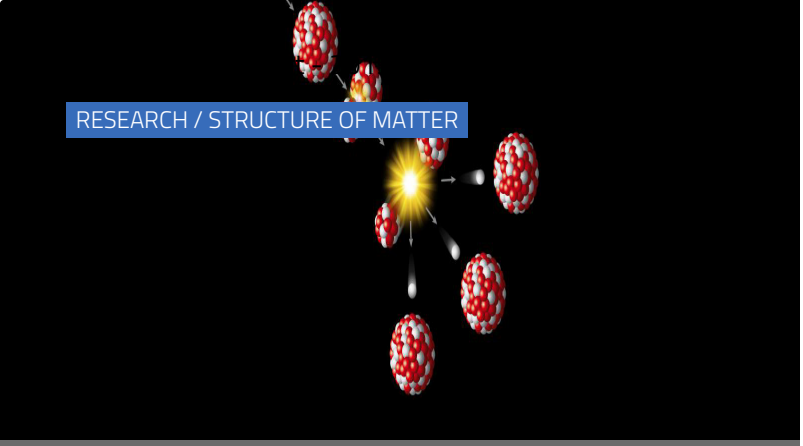
Weaknesses & threats

- The reduced number of team members and their commitments with other project.
- 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.

Publications

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

- *"Probing dense baryon-rich matter with virtual photons"*, HADES Collaboration, Nat. Phys. 15 (2019) 1040



NUC-RIA

Experimental Nuclear Astrophysics

Principal Investigator:
Daniel Galaviz (100)

3 ***PhD Student(s):***
Elisabet Galiana (100), Pamela Teubig (80), Paulo Velho (100)

2 ***Master Student(s):***
Francisco Barba (100), Manuel Xarepe (55)

4 ***Trainee(s):***
Joana Rebelo, José Nunes, Luísa Baptista, Ricardo Pires

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

Total FTE:
5.4

Articles in international journals:
1 Direct contribution
1 Indirect contribution
Completed theses:
1 PhD

Executive summary

During this year, the group has continued working on the two main research lines, devoted to fundamental studies of nuclear reactions, both at relativistic energies and low energies (around the Coulomb barrier:

The so-called Phase-0 experimental phase of the FAIR laboratory started in 2019, with the group contributing during this year to the preparation and execution of the first FAIR experiments within the R^3B collaboration. Continuing within the CALIFA working group, contributions to the benchmark of the first demonstrator modules of the detector, as well as to the assembly of a large part of the calorimeter, were performed by members of the group, directly working at GSI. Additional approaches to bring the LIP's expertise on scintillating fibers for the detection of heavy ions at R^3B have been performed during the past year. Our goal is to continue our involvement within the collaboration and participate in the study of halo nuclei using the newly available liquid hydrogen target. These measurements are however only foreseen for 2021. Along this line of work, Paulo Velho defended his PhD Thesis on knock-out studies at R3B last December 2019.

The low-energy branch of the group has been more active this year. Members of the group have participated/contributed to reaction experiments with stable (CTN-Lisbon, CNA-Seville, LNS-Catania) and radioactive (TRIUMF-Vancouver) ion beams at energies around the Coulomb barrier. The experimental line leaded by the group for the measurement of alpha scattering in inverse kinematics at LNS experienced some delay caused by the production of the solid 4He targets. These problems were solved and the experiment is scheduled to run in March 2020. In addition, experimental campaigns for the measurement of photon production in stable Chlorine isotopes were performed at the CTN laboratory in Lisbon, covering for the first time the relevant energy range for IBA techniques.

Overall, the group has experienced a growth at the student level, attracting students (4) from the University of Lisbon to work for their MSc. projects in engineering physics in the fields of instrumentation and nuclear reaction studies.

Sources of funding

PI	Code	Amount	Dates	Description
Daniel Galaviz	CERN/FIS-PAR/0005/2017	24.640 €	2018-07-01 / 2020-06-30	PORTUGAL at ISOLDE

Total: 24.640 €

NUC-RIA

Lines of work and team organization

The group has not changed its structure, with Daniel Galaviz as main researcher and without additional researchers with a PhD. It has however grown in terms of young members, with 2 PhD candidates, 4 MSc. candidates and additionally 2 students at the BSc. level. The lines of work can be summarized in two:

- High-energy reactions and data analysis on exotic nuclei at R^3B/FAIR.
- Low-energy reactions on stable and unstable nuclei for nuclear astrophysics.

The PhD candidate Paulo Velho defended his PhD Thesis on December 2019. He will continue the collaboration with the group, contributing to the high energy reaction branch.

Stated objectives for past year

- Participation at R3B Day-Zero experiments.
- Alpha elastic in inverse kinematics at LNS.
- Preparation and eventual execution of S442.
- CALIFA tests at CTN.
- National grant application for ISOLDE/CERN.
- Participation in the ERINS consortium.

Achievements and responsibilities during the past year

- Day-Zero experiments at FAIR: following the preparations for the first benchmark experiment of R3B at FAIR, under the acronym S444, members of the group have participated in the first series of measurements with the upgraded setup. The main part of the work focused on the performance of the CALIFA calorimeter. Contributions to the mounting of the whole CALIFA barrel detector were also performed by members of the team.
- Inverse alpha elastic scattering at INFN/LNS:
- Participation in S1847 experiment at TRIUMF:
- Measurement of PIGE at CTN:
- Gamma natural background characterization:

Lines of work and objectives for next year

The group suffered from a severe drawback at the end of last year, as the application for funds to the CERN Fund call from FCT was not successful. The consortium built around the activities in low-medium energy nuclear physics, including aspects of instrumentation (scintillating fibers for heavy-ion tracking) and hadronic theory, was not able to convince the jury to support the proposed activities. Solely some participation in the project proposed around RPC activities was positively evaluated, with applications of thermal neutron detection for nuclear astrophysics studies considered. Additionaly, the proposal for the continuation of the ENSAR2 Infrastructure Program, under the acronym ERINS (European Research Infrastructures for Nuclear Science), was not successful, with associated uncertainty related to when the next application will be possible. This also implicated a severe drawback for the group, as the funds available to access European Accelerator Facilities were used by members of the group to keep up its experimental activity.
Plans to overcome the situation implies the participation in a joint application (national level) for nuclear science, focusing on the work at the high energy branch, in collaboration with the new theoretical group NPStrong of LIP. Future applications for the CERN FCT Fund are also planned in two years from now, aiming at covering the low-energy activities at ISOLDE and related laboratories. Considering the current situation, the list of topics expected to be covered by the research group are the following:

- Participation at R3B Day-Zero experiments: Continuing with the initial FAIR program, and whenever funds available, we plan to continue our contribution to the R3B Day-Zero program. Experiments are scheduled during the first half of 2020.
- Alpha elastic in inverse kinematics at LNS: The proposed and approved experiment to measure the elastic scattering of nickel isotopes on 4He nuclei in inverse kinematics is scheduled now to run in March 2020. In close collaboration with the Seville and Catania groups participating in the proposal, we will lead the execution of this first line of measurements, with possible continuation over the years to come in Catania, and extension to radioactive nuclei at the HiE-ISOLDE facility after LS2.
- Resubmission of experimental proposal S442: Due to technical difficulties in the first phase of measurements of R3B, the consortium around the approved experimental proposal S442 decided to postpone the measurement to a later stage. The management of the FAIR laboratory requested to all approved and not yet performed measurements, to resubmit their proposals for evaluation. This will be done in the first half of 2020. The group will join the consortia about the measurement of knock-out reactions on light isotopes, trying to continue and advance with this research line.
- Analysis of PIGE data from CTN: The conclusion of the analysis of the performed measurements at the CTN laboratory around the study of proton induced reactions on chlorine isotopes will be concluded during 2020. The results will be made available to the community of ion beam analysis techniques, and the first steps towards the implementation of Proton Induced Gamma-ray Emission processes in GEANT4 will be as well done in the framework of the PhD Thesis of Elisabet Galiana.

- Analysis of PIGE data from CTN: The conclusion of the analysis of the performed measurements at the CTN laboratory around the study of proton induced reactions on chlorine isotopes will be concluded during 2020. The results will be made available to the community of ion beam analysis techniques, and the first steps towards the implementation of Proton Induced Gamma-ray Emission processes in GEANT4 will be as well done in the framework of the PhD Thesis of Elisabet Galiana.
- Low-energy proton capture at CTN: In the framework of the Master Thesis of Manuel Xarepe, the group will prepare and execute the measurement of low-energy proton capture reaction studies on the 118Sn isotope, at the CTN laboratory. The innovative measurement will allow to constrain studies of stellar nucleosynthesis, as well as may open a new line of research using the activation technique in Lisbon.
- Events in Fall 2020: In addition to the participation of the organization of the PANIC 2020 conference, hosted by LIP, and to the FISICA 2020 national conference, organized by the Portuguese Physical Society (SPF), the group will be responsible for the organization of the annual "NUSTAR Week 2020" meeting in Lisbon. The NUSTAR (Nuclear Structure, Astrophysics and Reactions) collaboration, one of the 4 scientific pillars of the FAIR facility, decided to organize its annual meeting outside Germany in Portugal. Members of the group will be directly involved in the organization of the meeting at the end of September at the Faculty of Sciences of the University of Lisbon.

Medium-term (3-5 years prospects

After some years being part of LIP, the group has stablished its activity around fundamental nuclear reaction physics. Recently, collaborations with other LIP branches like the simulation competence center, instrumentation groups (scintillating fibers, neutron detectors), 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.
We will aim at continuing collaborations with other European groups performing nuclear reaction studies for fundamental science. The involvement in consortia at the European level like the ERINS proposal for European Infrastructures, or collaborative networks within the COST framework, will be also in the scope of the activity of the group.

Publications

1 Articles in international journals

(with direct contribution from the team)

- *"beta decay of In-133: gamma emission from neutron-unbound states in Sn-133"*, IDS Collaboration, Phys. Rev. C 99 (2019) 024304

Theses

3 PhD

- Paulo Velho: *"Study of ground state properties of halo nuclei via quasi- free scattering reactions at the R3B setup at GSI"*, 2011-10-01 / 2019-12-05, (nished)
- 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)
- Elisabete Galiana: *"Analysis and simulation of (p,g) and PIGE low energy reactions: An ENSARRoot development"*, 2018-01-01 , (ongoing)

1 Master

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

SWOT analysis

Strengths

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

Weaknesses

Just one 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 the group is involved in.

Opportunities

The participation in the consortium ENSAR2 of Horizon2020 allows the participation and active involvement in nuclear reaction experiments performed in radioactive and stable ion beam facilities in Europe until August 2020. Its possible renewal in the upcoming times (LIP as one of the Portuguese beneficiary institutions) would constitute a clear opportunity to advance. The ChETEC COST activity also opens a spectrum of opportunities in the field of Nuclear Astrophysics.

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 contribution, future participations in this facility and the frontier physics that will be performed are under threat.

NPSTRONG [x]

Nuclear Physics and Strong Interaction Group

Principal Investigator:
Teresa Peña (100)

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

2 *Master Student(s):*
Madalena Lourenço (100), Manuel Fortunato (100)

1 *Trainee(s):*
Pedro Duarte, João Silva

Total FTE:
3.1

(x) Starting in 2020

Executive summary

NPStrong, Nuclear Physics and Strong Interaction Group, is a well established group that joined LIP only recently (2020). It comprises scientists with common research interests in Nuclear and Hadron Physics.
We use nonperturbative functional methods (in contrast to a lattice discretization) to find solutions of Quantum Chromodynamics (QCD) for bound systems of quarks and gluons. These methods are complementary of lattice QCD simulations (LQCD) and provide ab-initio solutions for QCD's correlation functions which subsequently enter in the calculation of hadron observables, where the soft and hard scales are intertwined by nonperturbative integral equations.
Applications include hot topics such as the nature of the recently discovered tetra- and pentaquark states, which are not yet understood within the framework of the traditional constituent quark model. We are also interested in determining the production mechanisms and properties of other exotic hadrons (such as quark-gluon hybrids and glueballs), as well as the spectra and internal structure of "ordinary" mesons and baryons, how they decay and couple to photons.
Big motivating questions of this activity are the origin of con nement 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.

NPStrong

Lines of work and team organization

- Bound states and resonances in nonperturbative quantum field theories that generate quark and gluon correlation functions and vertices.
- Spectroscopy and structure properties of mesons and baryons
- Multiquark systems
- Dynamical Chiral Symmetry Breaking and quark mass functions in dynamical quark models

Achievements and responsibilities during the past year

We highlight two main achievements of the year 2019. They relate to innovative methodology for interpretation of experimental data.
X(3872) as a four-quark state:
Bethe-Salpeter amplitudes for the quantum numbers I(JPC) = 0(1++) of the X(3872) were represented by a basis of heavy-light meson-meson, hadro-charmonium and diquark-antidiquark operators, were calculated for a dynamical distinction between different internal configurations. In both cases we find the heavy-light meson- meson component to be dominant. For the putative X(3872) we obtain a mass of 3916(74) MeV; the corresponding state is predicted at 4068(61) MeV.
Scattering amplitudes and contour deformations:
We showed that there is no difference between results from approaches based on Euclidean metric (like Dyson-Schwinger-Bethe Salpeter, DSBS, methods or lattice QCD calculations) or Minkowski space approaches (like in light front approaches, or 3-dimensional reductions of DSBS equations). To obtain scattering amplitudes in the complex plane, contour deformations are necessary both in a Euclidean and Minkowski metric. When implemented properly, the resulting amplitude obtained with a Euclidean path deformation is identical to the Minkowski space amplitude.
Also, there is a typical obstacle in the functional approach DSBS equations to determine hadronic observables: the location of resonances it is necessary to access unphysical Riemann sheets, whereas straightforward numerical calculations are restricted to the first sheet only. Within a scalar theory with a scalar exchange model, we calculate the $2 \rightarrow 2$ scattering amplitude and its homogeneous Bethe-Salpeter (BS) amplitude and inhomogeneous BS vertex. We showed that the eigenvalues of the homogeneous BSE are sufficient to extract the resonance information, solving the annouced obstacle. Although the model does not produce resonances above threshold but virtual states on the second Riemann sheet, posing difficulties for standard analytic continuation methods, by solving the scattering equation directly and employing the two-body unitarity property, enabled us to calculate the scattering amplitude also on the second sheet.

Lines of work and objectives for next year

Experimental evidence for multiquark states in the charm region has accumulated through observations at LHCb. Although these configurations cannot be described as simple quark-antiquark or three-quark states, they are not ruled out by QCD. One of the main questions is then: how can the inner clusters of multiquark systems, either compact or molecular-like, be understood as emerging from QCD in terms of quarks and gluons? Using nonperturbative covariant frameworks in QCD will allow us to investigate the properties of tetraquark and pentaquark states and make predictions for new states to be experimentally validated.
Multiquark components in hadrons cannot neither be considered in Standard Constituent quark models, nor calculated by LQCD simulations. These methods provide ab-initio solutions for QCD's correlation functions which subsequently enter in the calculation of hadron observables, where the soft and hard scales are intertwined by nonperturbative integral equations. Current efforts focus on the structure of the proton, which is studied at COMPASS, meson and baryon excitations including the extraction of resonance properties and scattering amplitudes, hyperon physics, which is a central topic of ALICE, as well as tetraquark, pentaquark and multiquark systems studied by ALICE and LHCb.

Medium-term (3-5 years) prospects

The strong interaction described by Quantum Chromodynamics (QCD) binds quarks and gluons to hadrons, but it is also responsible for binding protons and neutrons to nuclei. Our expertise in the DSBS approach and their variants opens up the possibility to investigate how short-range nuclear correlations (SRC) emerge microscopically, and induce exotic behavior at the level of nuclei. Very recent electron scattering experiments by the CLAS Collaboration, running from 4He to 208Pb, showed that SRC are „isophobic": similar nucleons are much less likely to correlate than different ones to form close-proximity (or high relative momentum) pairs, leading to many more of neutron-proton (np) correlated pairs than nn and pp pairs, as much as 20 times. In addition, the fraction of the protons with high relative momentum increases with the neutron excess in the nucleus.This means that in heavier nuclei protons (made of uud quarks) are much likely than neutrons (made of ddu quarks) to have a distorted quark structure. In nuclei then, there is a larger
modification, on average, of u quarks compared to d quarks. In turn this causes a difference between neutrino and antineutrino cross-sections in asymmetric nuclei, which could be misinterpreted as signs of physics beyond the Standard model or CP violation.

High-momentum nucleons are important in several phenomena and data in nuclear physics: neutron-rich systems and neutron stars, dissociation of Borromean drip-line nuclei, capture reactions important in the astrophysical processes of nucleosynthesis,etc. Final examples are nuclear parton distributions and changes in the distributions of nucleons bound in the nuclei (the EMC effect).

SWOT analysis

Strengths

- Unique expertise in DSBS non-perturbative methods and their variants, to treat QCD, allowing the extraction of weight of different multiquark components, which cannot neither be considered in Standard Constituent quark models, nor calculated by LQCD simulations.
- International collaborations.
- Use of complementary theoretical toolkits to probe model independence.

Opportunities

- NPStrong activity naturally connects with the activity of several Research groups at LIP and will create new synergies
- Obvious connection established by QCD between our research and the work developed by the Pheno group at LIP, since QCD supports a very rich bound state and resonance structure, as well as a rich phase structure at finite temperature and chemical potential that is under scrutiny by heavy-ion collisions.
- Astrophysical data from big mergers collisions, such as neutron stars, in the cosmos reinforce the interdisciplinary links between astroparticle, nuclear and particle physics. As these three fields unravel new insights in fundamental physics “per se”, NPStrong expertise is special at LIP and ideal for synergistic combination of the three fields, needed to address questions on the dark matter and neutrino sectors as well as on the physics of gravitational waves.

Weaknesses

- Reduced dimension of the group.

Threats

- Constraints in funding.
- International attractive alternative job offers for the younger members.

[Cosmic rays]

AMS
Auger
LATTES

RESEARCH / COSMIC RAYS

AMS

Collaboration in AMS - Alpha Magnetic Spectrometer

Principal Investigator:
Fernando Barão (60)

3 ***Researcher(s):***
Luisa Arruda (20), Paula Bordalo (73), Sérgio Ramos (73)

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

2 ***Trainee(s):***
David Lima, José Jesus

2 ***External collaborator(s):***
Laurent Derome, Nicola Tomassetti

Total FTE:
3.3

Articles in international journals:
1 Direct contribution
3 Indirect contribution
International conferences:
1 Oral presentation
Advanced Training Events:
2 Oral presentations
Seminars:
2 Outreach seminars

Executive summary

LIP is part of a broad international collaboration since 1998, that designed and operates the Alpha Magnetic Spectrometer (AMS). The project had two distinct phases: first a prototype was built and flewn 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 at least up to 2024.

Since May 2011, a large set of data has been gathered at a continuous rate of around 45 million events/day, corresponding now to around 152 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. On 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.

Following the launch of AMS on 2011, the group got involved on data analysis, with particular emphasis on variability studies of particle fluxes related to solar activity, already contributing to the area with a few papers studying not only the correlation between the sun and the cosmic ray flux but also the intrinsic propagation mechanisms present in solar modulation.

Throughout the year 2019 the group got (more) involved in deuteron/proton separation and flux analysis.

Sources of funding

PI	Code	Amount	Dates	Description
Fernando Barão	CERN/FIS-PAR/0020/2017	35.000 €	2017-09-01 / 2019-08-31	Collaboration in AMS - Alpha Magnetic Spectrometer
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: 85.000 €

AMS

Lines of work and team organization

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

1. RICH subdetector data reconstruction

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.

2. AMS data variability studies

Solar activity, varying in a periodic way, affects cosmic ray 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 that the LIP group is involved in the study of the solar modulation of the cosmic rays and in their interpretation under Solar modulation models.

3. Particle identification and isotopic measurements

The group has been also involved in data analysis involving particle identification, based on BDT or PDF techniques. Such tools were applied to anti-proton/electron separation and to isotopes identification.

4. AMS POCC activities

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

Stated objectives for past year

The main objectives of the group for 2019 were:

- to fulfill our engagement in the monitoring operations at CERN
- to monitor the reconstruction tools perfomance developed by the group
- to participate on the data analysis effort of AMS
  - variability studies of cosmic-ray fluxes (protons, ...)
  - nuclei selection and isotopic studies

Achievements and responsibilities during the past year

The group propositioned to work on the topics related to the detector AMS to monitor its performance, to study and interpret its measurements, (namely on the reconstruction of fluxes and their temporal analysis), as well as studying solar modulation in the context of AMS.

During the course of last year Fernando Barão (FB) and Miguel Orcinha (MO) performed shifts at AMS control centre (POCC) at CERN, Geneva, Switzerland.

The main goal of these shifts was the monitoring of the AMS detector installed on the International Space Station.
Due to this group's history with the RICH sub-detector, in addition to the regular shifter tasks, the members of these group were also expert on-call.

Related to AMS' measurements, the work being done on the time dependent proton flux was continued. The time-resolved proton 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 Laboratoire de physique subatomique et de cosmologie de Grenoble - LPSC), in collaboration with this group.

Additionally, in collaboration with another member of AMS and researcher of Istituto Nazionale di Fisica Nucleare - INFN, Nicola Tomassetti, some further work was produced and published interpreting cosmic ray data from AMS and studying different aspects of cosmic-ray's diffusive transport throughout the solar system, its relation to the solar activity cycle and the temporal variability of the cosmic-ray flux. This work relied on solving Parker's 1D cosmic-ray transport equations numerically. A fast new algorithm was developed together with students during their summer internships with the AMS/LIP group.

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.

On the topics of light isotope and nuclei identification the group worked on studying Tracker, RICH and ECAL measurements in order to develop identification tools. The group worked on both likelihood estimators and machine learning algorithms in order to separate deuterons from protons. This work has been developed with another AMS collaborator, Eduardo Bueno, from the AMS group at Groningen University in the Netherlands.
The group also developed machine learning algorithms to classify helium events and, using a template fit technique, estimate the ratio of helium-3 to helium-4 in the AMS cosmic ray flux. This work integrated undergraduate students.
This is a work which is currently ongoing and aligns with AMS' research efforts for the next years. Isotope selection and higher charge nuclei identification are topics of extreme relevance for AMS' future prospects.

These works were presented in AMS' Analysis Meetings and on several international conferences pertaining to cosmic ray Physics. The most recent contribution was made by FB in the "30th Texas Symposium on Relativistic Astrophysics" in Portsmouth, England, where he presented a talk titled "Cosmic-ray isotopes measured by AMS".

FB was also involved in the organization of several workshops on the topic of cosmic rays, aimed at undergraduate and graduate students, such as "Particles and Light" and "Hands-on in Cosmic Rays - Unveiling cosmic particles with muons: the cosmic connection".

Additionally the group participated in the organization of an international conference and several workshops, participated in several scientific divulgation activities for the general public, highschool and university students and contributed to schools of advanced formation, workshops and outreach sessions.

Lines of work and objectives for next year

Payload Operations and Control Center

AMS detector's perfect 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 head-quartered 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. The 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. These tasks have been undertaken by all AMS LIP members since the beginning of AMS operations in Space in order to guarantee the detector's performance and the good quality of the measurements. LIP is responsible for guaranteeing a "shifter" at CERN for 10 days every 2 months.

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 on 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 has 1H/2H and 3H/4H 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 cosmic rays can be directly correlated to solar parameters from a few months before.

Light isotope nuclei identification

Light nuclei like 1H and 4He (and CNO) are believed to be of primary origin. Rarer CR elements such as 2H, 3He (and Li-Be-B) are believed to be of secondary origin, i.e. produced by collisions primary of cosmic rays with the gas nuclei of the interstellar medium (ISM). The secondary cosmic-ray flux depend on the abundance of their progenitors nuclei, their production rate and their diffusive transport in the ISM. Thus, secondary to primary ratios are used to discriminate among propagation models. The comparison between radioactive and stable nuclei (e.g., Be-10/Be-9) will allow to estimate the halo size and the cosmic-ray Galactic confinement time (diffusion).

To distinguish deuterons from their background we need to develop statistical mass estimators, that will be used as template distributions for different velocity regions. Those estimators will use as inputs velocity and rigidity measurements as well as other detector variables like electromagnetic energy deposition, RICH ring signal, able to provide constraints to these distributions.
The statistical mass estimators to be developed must, in addition, take into account the geomagnetic cutoff that results from the fact that AMS-02 is orbiting around Earth and implies that particles are affected by the Earth's magnetic field in a different way, depending on the position of their impact point.

Additionally, the presence of a magnetic field at Earth, induces different particle cutoffs depending on AMS orbital position and particle arrival direction. It could be explored to separate isotopes by establishing velocity exclusion regions. This would be an interesting path to take after validating the separation algorithm.
This constitutes an innovative step to be developed that could validate the separation algorithm.

The deuteron signal is expected to be about one hundred times less abundant than its background (protons) while the antideuteron selection is expected to be about 1 million times less abundant than the background. This requires to combine the signals collected by the different AMS-02 sub-detectors, in particular the RICH, TOF and Silicon Tracker.
Since a large variety of variables must be combined, selection can be optimized by developing a machine learning algorithm.
The AMS/LIP group expertise on the RICH detector will be useful to identify the best variables. The data selection developed to the deuteron analysis can be later applied to the antideuteron searches.

Medium-term (3-5 years) prospects

AMS has been monitoring the current (24th) solar activity cycle a little past its minimum (between 2008-2010) through the solar axial magnetic dipole reversal (around 2013) and will continue to be operational during the next reversal (estimated to be in 2023), thus observing with great detail more than one total solar activity cycle. The next (25th) cycle is predicted to start around April, 2020.
This level of detailed observation is unprecedented. The group intends to remain focused on this topic of flux variability and the study of solar modulation, increasing its footstep on both interpretation and modelization.

In terms of temporal variability one can study the different time scales presented in the flux. Different periodicities can be extracted from cosmic-ray data and correlated to solar parameters in order to better understand solar wind and the diffusive propagation of cosmic rays in it. The group intends to analyse temporal variations in isotope fluxes.

The simulation of the propagation of cosmic rays in the heliosphere is a topic of interest since it allows for direct comparison of the idealized diffusion and drift mechanisms with experimental data. The development of these models and extending them to cover the wide range of parameters and transitions present in the solar activity cycle is a big point of interest for this domain of physics, specially during the solar magnetic dipole reversal.

The group also intends to keep its involvement in isotopic separation due to the group's experience with both the RICH detector and with data-driven likelihood models applied to particle identification and separation. The topic of isotopic separation is of particular interesting to astrophysical and dark matter studies since it greatly contributes to better understanding the propagation mechanism of cosmic rays in the galaxy.

The topic of isotopic separation also poses as a great opportunity to explore new separation techniques like using the geomagnetic cutoff effect to build mass templates.

SWOT analysis

Strengths

It is a highly experienced team in both experimental physics and astroparticle physics topics.

It keeps international relationships with several research laboratories in the field of study of the group. It has extensive computational skills spread throughout several platforms, OS's and programming/scripting languages.
It has experience in numerical resolution of physical problems and multivariate analysis techniques.

It developed in collaboration with one other laboratory a very well sedimented analysis framework with high capacity for expansion and adaptation, already in use on an international level by other members of the AMS collaboration.

Weaknesses and Threats

The main weakness, which is also a major threat, is the low funding attributed combined the small size of the group.

Opportunities

AMS keeps being a unique observatory in space. The increased interest by the scientific community in topics such as dark matter origin and cosmic anti-matter brings AMS to the spotlight as being an extraordinary source of knowledge. Due to AMS' high exposure time, nucleon and anti-matter fluxes are now able to be studied with sufficient accuracy due to the sheer amount of data. Another emerging topic in the international scientific community is time-variability of cosmic ray fluxes.

AMS

Publications

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

- *"Numerical modeling of cosmic-ray transport in the heliopshere and interpretation of proton and helium fluxes in Solar Cycle 24"*, N. Tomassetti, F. Barao, B. Bertucci, E. Fiandrini, M. Orcinha, Advances in Cosmic-Ray Astrophysics and Related Areas, Volume 64, Issue 12, (2019)

Presentations

1 Oral presentations in international conferences

- Fernando Barão: *"Cosmic-ray isotopes measured by AMS"*, 2019-12-15, 30TH TEXAS SYMPOSIUM ON RELATIVISTIC ASTROPHYSICS, Portsmouth, England

2 Oral presentations in Advanced Training events

- Miguel Orcinha: *"Study of solar modulation effects on cosmic ray fluxes measured by the AMS experiment"*, 2019-07-02, 5th IDPASC/LIP Students Workshop, University of Minho, Braga, Portugal
- Luisa Arruda: *"Radiação de origem cósmica"*, 2019-07-08, Workshop Hands on Particles and Light for Life, IST, Lisbon

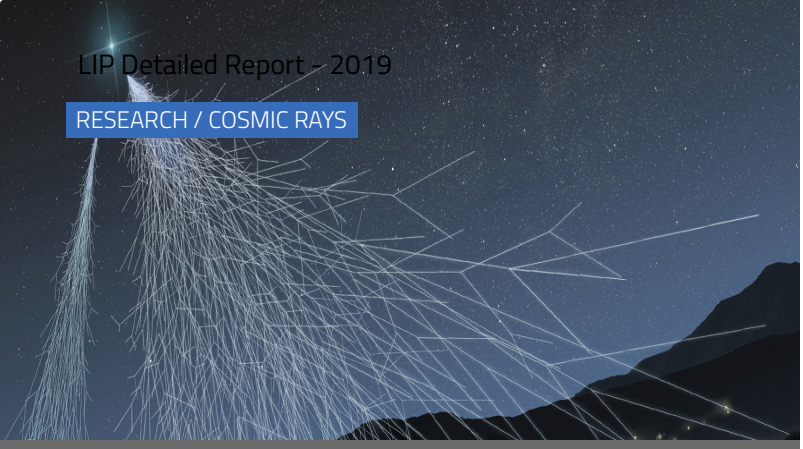
2 Outreach seminars

- Fernando Barão: *"Observar é Medir"*, 2019-02-20, , Esc Sec Filipa de Lencastre
- Fernando Barão: *"Observar o invisível"*, 2019-03-15, , LIP - Lisboa

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 (68)

15 ***Researcher(s):***
Alberto Blanco (10), Alessandro de Angelis (8), Bernardo Tomé (48), Catarina Espírito Santo (20), Felix Riehn (100), Gonzalo Parente (45), Helmut Wolters (20), Liliana Apolinário (15), Lorenzo Cazon (100)[*], Mário Pimenta (30), Patrícia Gonçalves (20), Pedro Abreu (63), Raul Sarmento (100), Ruben Conceição (50), Sofia Andringa (40)

4 ***Technician(s):***
José Carlos Nogueira (71), Luís Lopes (17), Luís Mendes (71), Miguel Ferreira (71)

2 ***PhD Student(s):***
Pedro Teixeira (83), Ricardo Luz (83)

1 ***Undergraduate Student:***
Pedro Gabriel

2 ***Trainee(s):***
Leonardo Ramalho, Pedro Branco

3 ***External collaborator(s):***
João Espadanal, Maria Belén Andrada, Miguel Martins

Total FTE:
11.4

Articles in international journals:
4 Direct contribution
1 with internal review by the team
3 Indirect contribution
Internal notes:
3 Collaboration notes
International conferences:
7 Oral presentations
1 Poster
9 Proceedings
National conferences:
1 Oral presentation
International meetings:
11 Oral presentations
Collaboration meetings:
7 Oral presentations
Advanced Training Events:
4 Oral presentations
Seminars:
2 Seminars
11 Outreach seminars

(*) Co-PI

Executive summary

The Pierre Auger Observatory, the largest Cosmic Ray 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 about the Physics governing interactions at the highest energies. The Collaboration is performing an upgrade which is expected to increase the data quality and will operate at least to 2025.

One of the most exciting results is the experimental proof that at the highest energies (~10^{20} eV) the cosmic-ray flux is strongly suppressed. 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 CMB photons in their voyage to Earth. Extensive Air Shower parameters sensitive to the mas of the primary Cosmic Ray 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 with the Earth's atmosphere are not tested by man-made accelerators, resulting in the dominant uncertainty in the description of Extensive Air Showers, which thus hampers the comprehension of the whole UHECR picture.

The Auger full detector upgrade, consisting on the installation of scintillators on top of the existing Water Cherenkov detectors and on the upgrade to faster electronics, aims at providing a better knowledge of the different components of EAS. A great effort is being done in next-generation analysis and in the development of phenomenological models to attain a good description of the Air Shower observables and thus understand their development. The muonic component plays a big role as it can probe directly the hadronic component of the shower 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, at a lower energy, the full array measurements.

The LIP team has been deeply involved in the last years in the development of the MARTA project, a joint Portugal-Brazil effort, to measure directly the muon content at the shower front using RPC detectors installed beneath the Water Cherenkov Detectors. Low flux RPCs developed at Coimbra were built in cooperation with Brazilian institutes and its first data is foreseen for 2020. Prototypes have been working on a regular basis at Malargüe.

MARTA detectors will be used for a deeper understanding of 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, interactions closer to the LHC centre-of-mass energies).

The LIP team expertise in shower physics has allowed to develop models and innovative methods that will allow the team to give relevant contributions in the analysis of the Auger new data. Namely it has unveiled the relation with the interactions that take place at early stages of the shower development through the analysis of the shower-to-shower muon fluctuations, which is now being analysed, and is leading ongoing efforts to measure the muon content of showers.

Sources of funding

PI	Code	Amount	Dates	Description
Lorenzo Cazon	IF/00820/2014/CP 1248/CT0001	50.000 €	2015-01-01 / 2019-12-31	Expl. 2015 LC - IF/00820/2014/CP1248/CT0001
Pedro Assis	CERN/FIS-PAR/0023/2017	150.000 €	2017-05-02 / 2019-08-31	Participação portuguesa no Observatório Pierre Auger
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: 410.000 €

Auger

Lines of work and team organization

The Portuguese group in Auger is active both in the detailed study and development of the detectors to improve the data quality and on the data analysis and model development in which several important results have been achieved.

The group is mainly focused on the full exploitation of the particle physics potential of the Observatory, 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 the understanding the relationship of the properties of the very first interactions with the observable muon content on the development of the EAS.

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.

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

Currently, L. Cazon is leader of the Shower Physics Task of Auger, and P. Assis is leader of the Calibration task. S. Andringa is a member of the Conference Committee.

Stated objectives for past year

In 2019 it was expected to have the first data from the MARTA Engineering Array and some extra stations deployed in the field. It was also planned to have established the framework for the MARTA project, including the simulation and the data infrastructure. The relation with AMIGA and common analysis, sharing data and inter-calibration were to be pursued.

One of the work lines as a result of the MARTA effort would be to pursue the characterization of other detectors, namely the response of the Water Cherenkov Detector to isolated muons. The inter-calibration with AMIGA and the upgrade detectors was also stated as an objective.

R&D in gaseous detectors was also a line of development in strong cooperation with the group working in RPCs and the Lattes group.

Several studies on the phenomenology of Air Shower Cascades and the relation between fundamental properties of interactions occurring at the very first part of the development of the shower with the observable on ground were to be studied and new observables defined.

The muon component on ground, estimated with the current detectors, was to be characterized, focusing on the mean number of muons on ground and on the fluctuation of is number.

A strong effort in the outreach of the experiment and on the measurement of Cosmic Rays was foreseen, focusing on the development of simplified analysis tools and of guidance scripts for masterclass-like sessions with students from high schools.

Achievements and responsibilities during the past year

In 2019 the group had a major breakthrough with the installation with the first MARTA station on the field. The hardware for this station was fully installed by a LIP team with some help from the observatory staff and the generosity of the AMIGA group. Unfortunately, during the installation, it was identified a small problem in the slow control subsystem that prevented the operation of the station. A solution was readily developed and will be deployed in the next visit to Argentina in early 2020.

The construction and deployment of the support structures for the MARTA stations had also a great boost and only two stations are missing the pre-installation. These are also test stations used for the prototype tests of the Auger Prime upgrade.

On the simulation and analysis framework it was possible to develop and install in the official Auger OffLine simulation code the MARTA station, enabling the simulation of the array including MARTA station and to perform the analysis of the data. At the same time the data format was also defined. Data will follow a different path of the standard data but will be merged at some point in the general software framework, enabling combined analysis with the other detectors. Discussions with the AMIGA groups have already started to discuss combined analysis with the buried muon detector and inter-calibration of the detectors

Profiting from the new electronics developed a setup for the test of Scintillators of Auger Prime was setup and the Gianni hodoscope was also upgraded. These setups allow also for the testing of RPCs before the deployment on the field. The data acquired from the Gianni setup on the detailed characterization of the WCD response and on the calibration is the subject of a publication being finalized that will be submitted in early 2020. In this contribution we show that the simulation recreates the response of the tank to the percent level and that no ageing or modification on the calibration procedure was seen.

Studies on the phenomenology of the EAS has been pursued and several important results have been produced by the group. The group is focused in understanding driving parameters of the development of the shower. Several important developments, including the measurement of the muon content fluctuations and the probing of the energy spectrum of neutral pions on the first interactions of EAS, have been presented within the collaboration and are being prepared for publication. The group has also had a strong impact on the CR community presenting these results at the ICRC. The group has also led a multiexperiment working group which includes the 8 leading cosmic ray experiments at the highest energies, which has reported an increase of the muon excess in data with respect to simulations with the primary energy.

LIP has been an important partner in the outreach effort, leading the effort to develop a master-class program with Auger data. Preliminary versions of the scripts have been developed and are being tested and adapted with groups of high-school students.

Lines of work and objectives for next year

2019 marked the installation of the first MARTA station and 2020 will mark the start of MARTA operation. We foresee to have in early 2020 the first station providing data. We also foresee during this year the installation of about 4 or 5 more MARTA stations. We will also have the production of the remainder RPC modules in Brazil to finish the installation of the MARTA Hexagon.

Following the developments on the simulation framework we will have a strong program to simulate the detector, prepare the first analysis and predict the results of this detector. It will also be of fundamental importance for cross-tests and calibrations with other Auger detectors. First data should undergo the same processing and analysis as simulation results.

The SD detailed characterization will continue to be studied. We will focus on the Calibration of the tanks, and its inter-calibration with MARTA and AMIGA, a buried scintillator detector. We will also start the operation of the upgraded Gianni test setup which will allow to probe specific trajectories of muons in the tank, e.g. trajectories maximizing direct light.

The group will also make a great effort on the study of the EAS properties. Ongoing publications will be finished and submitted. As a follow up we will try to understand the possibility to measure the pion energy distribution in the first interactions from the Auger data. This work will be tested by introducing detector effects and then data will be exploited.

We will also develop analysis to characterize the muon content of the Air Showers and extract information about its development. We will exploit the data from the new detectors with higher purity and resolution.

The outreach effort will be continued developing and testing the new masterclass activities. We foresee to have the first session during 2020 which we will then propagate through the different groups. We expect to be able to organize in the medium-term international sessions with the simultaneous participation of several institutions, with a final teleconference to share the results obtained in the different institutes.

In addition, a collaboration with the Ciência Viva centre at the Mina of Lousal, in Alentejo, has allowed the installation of several RPC's prototypes and it is being used as a platform to introduce the topic of Cosmic Rays to a large segment of the society.

Medium-term (3-5 years) prospects

The understanding of the nature of the Cosmic Rays and the particle interactions at the highest energies are of paramount importance to further advance the knowledge and Pierre Auger Observatory is currently the best experiment to perform such studies. At Auger, LIP plays a key role in the analysis of the hadronic component of Extensive Air Showers, mainly through muons, which the group will pursue in the following years. On one hand, the group is leading the MARTA project - Muon Array of RPCs for Tagging Air-showers to enhance muon detection capabilities whilst on the other is developing sophisticated analysis strategies to study the muon content and interpret its results regarding hadronic physics taking place at the higher energies. These works are also connected with shower phenomenology studies, relating interaction parameters with observables at the ground. These leadership roles are also translated on the Calibration and on the Air Shower Physics Tasks, which have members of the group as coordinators.

In the next years, the MARTA engineering array will be installed in a region of Auger dedicated to lower energy cosmic rays, thus providing high statistics despite its modest size. Here, it will be operated in coincidence with the standard Auger detectors, the upgrade's scintillator and the AMIGA buried detector. Cross-calibration and study of the performance of all detectors of paramount importance for the Observatory in which the group will engage, taking a key role.

The group will continue the studies in the hadronic sector of the Extensive Air Showers, probing interactions at the highest energies. The group will also study in detail the relation of the muonic cascade with the nature of the primary and with early interactions leaning on the vast expertise in muon measurement techniques. MARTA will allow, for a limited sample of events, to have a clean measurement of the muon content and time structure thus enhancing not only the estimation of the muon content but also to assess parameters governing the early shower development. Moreover, MARTA will be able to probe the energy region where there is an overlap with LHC and where hadronic interaction models start to fail predictions on the number of muons. Hence, the exploration of the muon EAS content at MARTA is in a privilege position to finally solve the so-called muon problem in CR.

AugerPrime, with its upgraded capabilities, will allow not only to improve our understanding of the Air Showers but also the response of the different detectors. New analysis will come into play, which once validated, can be used to reprocess previous collected data and increase the exposure.

Moreover, the understanding of the muon and electromagnetic component relation will boost the knowledge of the nature of primary Cosmic Rays and permit a boost on the multi-messenger astrophysics.

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 poles, with the involvement of the Coimbra RPC team and the Minho analysis team.

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

MARTA detectors have proved already their capabilities for running in harsh environments showing RPCs are suitable to be used in CR environment. Most of the necessary pieces for the deployment of the Engineering Array are produced.

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

Weakness

The team has a rather small number of master and PhD students which leads to lack of workforce on some of the existing tasks and namely for the development of new lines of work.

The funding level of the group is low for the number of team members and the responsibilities within the collaboration and the MARTA project. Meetings and eldwork 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 Physics program and participation in thematic schools is increasing the awareness of this field. The LIP Remote Control Room at Técnico has also signi cantly contributed.

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

Threats

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

Auger

Publications

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

- *"Measurement of the average shape of longitudinal profiles of cosmic ray air-showers at the Pierre Auger Observatory"*, The Pierre Auger Collaboration, A. Aab et al, J. Cosmol. Astropart. Phys. 3 (2019) 018
- *"Long term experience in Autonomous Stations and production quality control"*, L. Lopes, A. B. Alves, P. Assis, A. Blanco, N. Carolino, M. A. Cerda, R. Conceição, O. Cunha, C. Dobrigkeit, M. Ferreira, P. Fonte, L. de Almeida, R. Luz, V. B. Martins, L. Mendes, J. C. Nogueira, A. Pereira, M. Pimenta, R. Sarmento, V. de Souza, B. Tomé, J. Instrum. 14 (2019) C07002
- *"Hadronic interaction model sibyll 2.3 c and inclusive lepton fluxes"*, Anatoli Fedynitch, Felix Riehn, Ralph Engel, Thomas K. Gaisser, and Todor Stanev, Phys. Rev. D 100, 103018
- *"Data-driven estimation of the invisible energy of cosmic ray showers with the Pierre Auger Observatory"*, Pierre Auger Collaboration, Phys. Rev. D 100 (2019) 082003

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

- Pierre Auger Collaboration: "Data-driven estimation of the invisible energy of cosmic ray showers with the Pierre Auger Observatory", Phys. Rev. D 100 (2019) 082003

9 International Conference Proceedings

- *"Measurements and tests of hadronic interactions at ultra-high energies with the Pierre Auger Observatory"*, Lorenzo Cazon for the Pierre Auger Collaboration, Proceedings of UHECR2018 held in Paris from 8-12 October 2018
- *"Average shape of longitudinal shower profiles measured at the Pierre Auger Observatory"*, So a Andringa and on behalf of the Pierre Auger Collaboration, Proceedings of UHECR2018, EPJ Web of Conferences, Volume 210 (2019)
- *"Probing the pion spectrum at high-x in proton-Air interactions at ultra-high energies"*, Lorenzo Cazon, Ruben Conceição, Miguel da Silva Martins, and Felix Riehn, EPJ Web of Conferences 210, 02006 (2019)
- *"Measurements and tests of hadronic interactions at ultra-high energies with the Pierre Auger Observatory"*, Lorenzo Cazon on hehalf of the Pierre Auger Collaboration, EPJ Web of Conferences 210, 02002 (2019)
- *"Working Group Report on the Combined Analysis of Muon Density Measurements from Eight Air Shower Experiments"*, Lorenzo Cazon, for the EAS-MSU, IceCube, KASCADE-Grande, NEVOD-DECOR, Pierre Auger, SUGAR, Telescope Array, and Yakutsk EAS Array collaborations, Pos(ICRC2019)214, proceedings of the ICRC2019, in Proceedings of Science https://pos.sissa.it/358
- *"Probing the High Energy Spectrum of Neutral Pions in Ultra-high-energy Proton-Air Interactions"*, L. Cazon, R. Conceição, M. Martins and F. Riehn, PoS(ICRC2019)226, proceedings of the ICRC2019, in Proceedings of Science https://pos.sissa.it/358
- *"Measurement of the fluctuations in the number of muons in inclined air showers with the Pierre Auger Observatory"*, Felix Riehn for the Pierre Auger Collaboration, PoS(ICRC2019)404, proceedings of the ICRC2019, in Proceedings of Science https://pos.sissa.it/358
- *"Probing High-Energy Hadronic Interactions with Extensive Air Showers"*, L. Cazon, PoS(ICRC2019)005, proceedings of the ICRC2019, in Proceedings of Science https://pos.sissa.it/358
- *"First results of the CORSIKA 8 air shower simulation framework"*, D. Melo, M. Reininghaus, F. Riehn, R. Ulrich, PoS(ICRC2019)399, proceedings of the ICRC2019, in Proceedings of Science https://pos.sissa.it/358

3 Collaboration notes with internal referee

- *"An opportunity to measure the high-x region of neutral pion production in UHE proton-Air interactions with Auger"*, Lorenzo Cazon, Ruben Conceição, Felix Riehn, GAP2019_001
- *"RPC hodoscope for SSD quality control"*, Ricardo Luz, GAP2019_017
- *"Muons in air showers at the Pierre Auger Observatory: Fluctuations of the muon number in highly inclined events"*, L. Cazon, R. Conceição, H. P. Dembinski, T. Pierog, F. Riehn, G. Torralba, M. Unger, I. Valiño, E. Zas , GAP2019_038

Presentations

7 Oral presentations in international conferences

- Ruben Conceição: *"Study of high-energy hadronic interactions with the Pierre Auger Observatory"*, 2019-06-25, International Symposium on Cosmic Rays and Astrophysics ISCRA2019, Moscow Engineering Physics Institute, Moscow, Russia
- Ruben Conceição: *"Probing the high-energy spectrum of neutral pions in ultra-high-energy proton-air interaction"*, 2019-06-25, International Symposium on Cosmic Rays and Astrophysics ISCRA2019, Moscow Engineering Physics Institute, Moscow, Russia
- Sofia Andringa: *"The highest energy particles at the Pierre Auger Observatory"*, 2019-07-02, PASCOS 2019 - XXV International Symposium Particle physics, String theory and Cosmology, Manchester, UK
- Lorenzo Cazon: *"Probing High-Energy Hadronic Interactions with EAS"*, 2019-07-29, 36th International Cosmic Ray Conference, Madison, WI, USA
- Lorenzo Cazon: *"Working Group Report on the Combined Analysis of Muon Density Measurements from Eight Leading Air Shower Experiments"*, 2019-07-31, 36th International Cosmic Ray Conference, Madison, WI, USA
- Felix Riehn: *"Measurement of fluctuations in the number of muons in inclined air showers with the Pierre Auger Observatory"*, 2019-07-31, 36th International Cosmic Ray Conference, Madison, WI, USA
- Ruben Conceição: *"Probing the high-energy spectrum of neutral pions in ultra-high-energy proton-air interaction"*, 2019-07-31, 36th International Cosmic Ray Conference, Madison, WI, USA

1 Poster presentations in international conferences

- Ricardo Luz: *"MARTA's DAQ system"*, 2019-09-05, Topical Workshop on Electronics for Particle Physics 2019, Santiago De Compostela, Spain

11 Oral presentations in international meetings

- Felix Riehn: *"Production of high energy neutrinos in the atmosphere"*, 2019-03-21, Workshop for Atmospheric Neutrino Production in the MeV to PeV range, Nagoya University, Japan
- Felix Riehn: *"Sibyll 2.3c"*, 2019-03-25, Institute for Cosmic Ray Research Workshop, ICRR, The University of Tokyo, Japan
- Felix Riehn: *"Measuring the pion production cross section in proton-air interactions"*, 2019-04-25, GRAND Workshop (remote), DunHuang, China
- Raul Sarmento: *"MARTA Engineering Array"*, 2019-04-26, 2nd joint Workshop IGFAE/LIP, Santiago de Compostela, Spain
- Felix Riehn: *"A measurement of the pion production cross section in proton-air interactions ?"*, 2019-04-26, 2nd joint Workshop IGFAE/LIP, Santiago de Compostela, Spain
- Lorenzo Cazon: *"Muon Tomography"*, 2019-04-26, Second joint Workshop IGFAE/LIP, Santiago de Compostela, Spain
- Mário Pimenta: *"LIP PAST, PRESENT and FUTURE, 2013 - 2018/19 "*, 2019-06-12, Lisboa, Portugal
- Sofia Andringa: *"Autonomous tRPC for Muon Tomography"*, 2019-09-10, IAEA - Technical Meeting on Non-destructive Testing Using Muon Radiography, Vienna, Austria
- Felix Riehn: *"Production of high energy neutrinos in the atmosphere"*, 2019-09-14, Diffuse Global Fit workshop (remote), Tokyo University, Japan
- Felix Riehn: *"Heavy-quark production and further recent developments in SIBYLL"*, 2019-09-30, Heavy-Quark Hadroproduction from Collider to Astroparticle Physics, Mainz Institute for Theoretical Physics, Johannes Gutenberg University, Germany
- Mário Pimenta: *"Astroparticles in Portugal"*, 2019-12-03, Meeting of the APPEC General Assembly, Lisboa, Portugal

1 Presentations in national conferences

- Pedro Teixeira: *"Tomografia de Muões - Dos Raios Cósmicos à Mina do Lousal"*, 2019-03-26, 11.º Simpósio de Meteorologia e Geofísica da APMG, Cascais, Portugal

4 Oral presentations in Advanced Training events

- Mário Pimenta: *"Cosmic Rays"*, 2019-05-31, IX IDPASC PhD school, Otranto, Italy
- Ricardo Luz: *" MARTA readout system"*, 2019-07-01, 5th IDPASC /LIP PhD student Workshop, Universidade do Minho, Braga, Portugal
- Leonardo Ramalho: *"Ampliação das funcionalidades de um visualizador grá co 3D do Observatório Pierre Auger"*, 2019-09-05, LIP Summer Student Programme Final Workshop, LIP, Lisboa, Portugal
- Pedro Passos: *"Análise dos dados públicos do Observatório Pierre Auger"*, 2019-09-05, LIP Summer Student Programme Final Workshop, LIP, Lisboa, Portugal

2 Seminars

- Luís Mendes: *"Instrumentação de física de partículas II: detectores a gás (RPC)"*, 2019-02-04, 4a Escola Avançada de Física Experimental do CBPF, CBPF, Rio de Janeiro, Brazil
- Felix Riehn: *"Particle physics at ultra-high energy"*, 2019-03-25, Institute for Cosmic Ray Research, University of Tokyo, Japan

11 Outreach seminars

- Mário Pimenta: *"Observar e Imaginar o Universo: Do século XIX ao século XXI"*, 2019-01-26, Centro Formação António Sérgio, Lisboa, Portugal
- Mário Pimenta: *"De que são feitas as coisas: Das Partículas ao Universo"*, 2019-02-01, Lisboa, Portugal
- Ricardo Luz: *"Partículas: do Universo ao Laboratório,"*, 2019-02-11, Sessão Pública para Escolas, LIP, Lisboa, Portugal
- Pedro Teixeira: *"Tomogra a de Muões - Dos Raios Cósmicos à Mina do Lousal"*, 2019-03-23, 15ª Edição das Masterclasses Internacionais em Física de Partículas, Universidade de Évora, Évora, Portugal
- Mário Pimenta: *"Introdução à Física de Partículas"*, 2019-06-18, LIP, Lisboa, Portugal
- Mário Pimenta: *"Mensageiros do Universo"*, 2019-06-19, IST, Lisboa, Portugal
- Pedro Teixeira: *"Tomogra a de Muões - Muões Cósmicos na Mina do Lousal"*, 2019-07-27, Atividade de Verão: Muões Cósmicos na Mina do Lousal, Centro Ciência Viva da Mina do Lousal, Portugal
- Pedro Teixeira: "*Tomografia de Muões - Muões Cósmicos na Mina do Lousal"*, 2019-08-17, Atividade de Verão: Muões Cósmicos na Mina do Lousal, Centro Ciência Viva da Mina do Lousal, Portugal

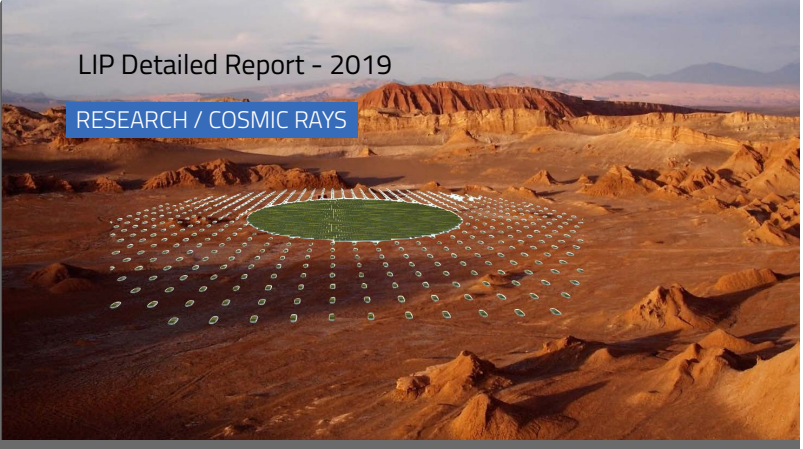
  Raul Sarmento: *"The Universe and Particle Physics"*, 2019-09-24, Universidade do Minho, Braga, Portugal
- Pedro Teixeira: *"Tomogra a de Muões - Muões Cósmicos na Mina do Lousal"*, 2019-10-09, O Espaço vai à Escola 2019, Escola Secundária Dr. João Manuel da Costa Delgado, Lourinhã, Portugal

  Sofia Andringa: *"Raios Cósmicos e Muões na Mina"*, 2019-11-27, Escolas Secundárias de Santiago do Cacém e Santo André

Theses

2 PhD

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



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 (9), Luís Lopes (15), Luís Mendes (15), Miguel Ferreira (15)

1 ***PhD Student(s):***
Ricardo Luz (9)

1 ***Master Student(s):***
Ricardo Lordelo (25)

3 ***Trainee(s):***
Hugo Lóio, Luís Lourenço, Wagner Silva

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

Total FTE:
4.1

Articles in international journals:
1 Direct contribution
International conferences:
2 Oral presentations
1 Poster
1 Proceeding
National conferences:
1 Oral presentation
International meetings:
1 Oral presentation
Collaboration meetings:
11 Oral presentations
Advanced Training Events:
2 Oral presentations
Completed theses:
1 Master

(x) Starting in 2020
(*) Co-PI
(+) Participation in the Competence Centre on Simulation and Big data within the project BigDataHEP included here

Executive summary

Present and planned large field-of-view (FoV) gamma-ray observatories are installed in the Northern Hemisphere, missing, in particular, the galactic centre, and have energy thresholds above 0.5 TeV.

The LIP-LATTES group, together with Padova, CBPF and MPKI groups, worked together to establish a joint project to design a ground array observatory able to monitor the Southern gamma-ray from 100 GeV up to 100 TeV. As a result, in May 2019, in a meeting at Lisbon, an international collaboration was formed, the Southern Wide-Field Gamma-ray Observatory (SWGO), which now joins already more than 100 scientists from 10 countries.

SWGO will be a powerful time-variance explorer filling an empty space in the global multi-messenger network of gravitational, electromagnetic and neutrino observatories. It will be able to issue pointing alerts to be thus fully complementary to the large next-generation imaging atmospheric Cherenkov telescope array, CTA. The construction of such experiment would allow to collect abundant and highly relevant data and play a fundamental role in the search for emissions from extended regions, as the Fermi bubbles recently discovered by the Fermi satellite or dark matter annihilation regions.

LIP has a leading role driving the efforts to access to the so-called sub-TeV gamma-rays, which would allow covering the energy gap in sensitivity between satellite bourne and ground-based measurements. Such endeavour has been mostly pursued in a 3-fold way: Explore the physics potential at the sub-TeV, in particular. regarding transient phenomena such as AGN flares and Gamma-Ray Bursts; Investigation of a new WCD concept with a matrix of photo-detector at the bottom and combined it with advanced Machine Learning techniques to improve the gamma/hadron discrimination; R&D of novel autonomous/low-flux RPC detectors to be used to calibrate the array detector units and the simulation used to train the ML algorithms.

The LIP project activities have been sustained by an FCT/PTDC funding approved in May 2018 for three years.

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

Total: 239.885 €

LATTES

Lines of work and team organization

The activities of the LATTES/SWGO Portuguese team are organized in four main lines of work:

Task 1 - Detector R&D

The main challenges to be addressed are: RPCs for operation at reduced atmospheric pressure and a gas flux of 1 cc/min; WCD operation at temperatures at which water and ice could be simultaneously present, which required a detailed thermal simulation.

Task 2 - Simulation and analysis

The main challenges to be addressed are: detector design optimization, by studying different detector configurations; development of improved analyses methods, with a particular focus in deep neural networks.

Task 3 - Phenomenology

The main challenges to be addressed are: transient phenomena (detectability of GRBs and AGN flares; multi-messenger events); extended sources (such as the Fermi bubbles and indirect dark matter searches).

Task 4 - Outreach

Develop materials for the exploration for educational purposes of gamma rays, including detectors to be used in demonstrations or installed in Science Centres.

Stated objectives for past year

Task 1 - Detector R&D

1.1 Build a hypobaric chamber and RPC prototypes optimized to operate at reduced atmospheric pressure.

1.2 Produce a detailed thermal simulation of the detector in the environment where the experiment should be installed (altitudes around 5000 meters in the Andes), in collaboration with the IST Mechanical Engineering department.

1.3 Study the evolution of the freezing point and the optical properties of sterilized water samples as a function of different solvent concentrations, using the setup already existing at LIP.

Task 2 - Simulation and analysis

2.1 Design optimization: study a new layout concept with a central core of WCDs equipped with RPC muon hodoscopes surrounded by a large number of similar WCDs. This layout will allow covering a substantially larger area, increasing the physics sensitivity.

2.2 Development of improved analyses methods for shower reconstruction and background rejection, namely:

Joint activities with a computer science group from Coimbra in the gamma/hadron discrimination using pattern recognition techniques;

Joint activities with the Granada group from the Physics and Computer Science departments on the identification of muons through WCD signal time traces.

Task 3 - Phenomenology

3.1 Investigate the detection probability curves of different classes of transient phenomena.

3.2 Review the studies on the detectability of extended sources.

Task 4 - Outreach

4.1 Participate in outreach sessions for the general public at Lousal and in high schools.

4.2 Carry out validation tests and operate the RPC hodoscope demonstrator to installed in the Lousal Mine.

Achievements and responsibilities during the past year

Being part of the newly formed SWGO collaboration did not change the main goals of the LATTES Portuguese group significantly, but instead, it allowed to intensify its previous lines of action. The collaboration recognized the intense activities of the group in Simulation & Analysis. As a consequence, one of the members of the Portuguese group is now the co-coordinator of the SWGO working group responsible for the creation of a common simulation framework to test different experiment concept.

Task 1 - Detector R&D

1.1 A small hypobaric chamber was built. The RPC prototypes optimized to operate at reduced atmospheric pressure will be made and tested using the hypobaric chamber.

1.2 A detailed thermal simulation of the water Cherenkov detector was developed, in collaboration with the IST Mechanical Engineering department.

This simulation will be used to study the thermal behaviour of the WCD in the expected environmental conditions (altitudes around 5000 meters in the Andes).

1.3 A setup was optimised to study the evolution of the freezing point and the optical properties of sterilized water samples as a function of different solvent concentrations.

Task 2 - Simulation and analysis

2.1 A new layout concept with a central core of WCDs equipped with RPC muon hodoscopes was considered and discussed within the SWGO collaboration.

2.2 Study of the possibility of distinguishing gamma induced showers from hadronic induced ones using solely the measured shower pattern at the ground. This work was developed with the computer science group from Coimbra, experts in machine learning algorithms.

Using a neural network it was possible to demonstrate, for showers with 1 TeV of reconstructed energy, that exists additional information on the shower patterns at the ground. This information can be used to further improve the gamma/hadron discrimination. The work has been published in a peer-reviewed journal.

Activities with the Granada groups from the Physics and Computer Science departments started. The main goal is to use machine learning techniques to analyse WCD signal time traces and identify the presence of muons.

Task 3 - Phenomenology

3.1 Using the previous estimates on the expected sensitivity of SWGO, classes of transient phenomena, such as GRBs and AGN flares, were investigated. The study used Fermi data extrapolating towards higher energies, possibly at the reach of SWGO. This work, which has been already submitted for publication, demonstrates the importance of SWGO to monitor these rare events and trigger CTA observations.

3.2 The studies on Fermi bubbles (extended sources) were reviewed and presented to the collaboration.

Task 4 - Outreach

4.1 Several outreach sessions for the general public have been done at Lousal Ciência Viva centre and in high schools.

4.2 The RPC hodoscope demonstrator has been installed in the Lousal Mine.

Lines of work and objectives for next year

LIP's group main goal within the collaboration continues to be the lowering of the energy threshold and define new strategies, of calibration and analyses, that further improve the experiment sensitivity.

Task 1 - Detector R&D

1.1 Build RPC prototypes optimized to operate at reduced atmospheric pressure. These prototypes shall be tested in the hypobaric chamber previously built.

1.2 The thermal simulation has been developed, but the available computational power limits the extraction of results. Strategies to improve simulation performance will be pursued. The new WCD station concept will be implemented, and the simulation is going to be benchmarked using a commercial software.

Task 2 - Simulation and analysis

2.1 The WCD concept of LATTES has evolved. As the SWGO experiment is going to be four times bigger, we have opted to have only one WCD as the unit station and use the RPCs as hodoscopes to be mounted in a small portion of the array, which would allow calibrating the simulation and the detectors.

Following discussions within the collaboration, the rectangular WCD station with 1.5x3 m^2 will now be cylindrical with a diameter of 4 m. This new concept will be implemented in the simulation and studied.

2.2 The height of the WCD is an important physics parameter which drives the cost of the experiment significantly. A detailed study between the height of the tank and the required light collection area will be made.

2.3 LIP will participate in the development of a common simulation framework which allows an adequate comparison between the considered detector concepts. Our group will be responsible for the reconstruction algorithms.

2.4 The partnership with the Computer Science group from Coimbra to explore the shower patterns at the ground will continue. The focus will be the application of this gamma/hadron discrimination technique at lower energies, where the muons are not sufficiently present to help.

2.5 Deepen the partnership with the Granada group (physics + computer science). This group is analyzing with machine learning techniques the WCD signal time trace to identify the presence of muons. At high energies, muons are the most efficient way to tag background showers. The success of this task will significantly impact on the choice of the detector concept. A master student recently joined this activity.

It should be noted while promising, the activities 2.4 and 2.5, relying heavily on the reliability of the input given to the machine learning algorithms. This uncertainty can be reduced by using data, from the RPC hodoscopes mounted in some of the WCD stations, strengthening the importance of activity 1.1.

Task 3 - Phenomenology

3.1 Continue to investigate the sensitivity of an experiment such as SWGO to transient phenomena.

3.2 First assessment of SWGO capability to perform cosmic ray composition analysis.

Task 4 - Outreach

4.1 Participation in outreach sessions for the general public and high schools.

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 in 3-years a comprehensive study on the best options to be taken to build such an experiment. LIP's activities will provide essential elements for this study and the elaboration of the final document. LIP is actively engaged in activities which would allow SWGO to access with high sensitivity the sub-TeV energy range. LIP is contributing to the design of the detector concept, simulation framework for 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's 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 on May 2021. The LIP-SWGO group is in good shape with well-defined strategies which should place it in a good position to apply to the next PTDC call.

SWOT analysis

Strengths

The team holds high-level expertise in cosmic-ray research and extreme energy phenomena, detector R&D, data analysis, simulation, air shower physics and phenomenology. In addition, the team has world-recognised expertise in RPC development and is involved in R&D for the construction of autonomous RPC for outdoor operation at very low gas flux;

The team has close links with other groups, namely: the CBPF Brazilian group in the Pierre Auger Observatory; the INFN-Padova high-energy gamma-rays group; the Czech group involved in Auger and CTA; the Granada Astroparticle group.

Weakness

Reasonably, Portugal will cover only a small fraction of the total cost of such an Observatory.

Opportunities

The energy threshold of the air shower arrays presently in operation or under construction remains very large and unable to bridge with data from satellite-borne experiments. In addition, all air shower arrays presently in operation or under construction are in the northern hemisphere. The observation of multi-messenger events, combining the detection of gravitational and electromagnetic waves, and high-energy neutrinos with gamma-rays, triggered a growing international interest in building such an observatory in South America. The proposed detector concept combined with machine learning techniques has a large physics potential.

Threats

It is an ambitious project that will imply large financial and human resources. In the present international panorama, it may not be easy to ensure them in a reasonable time.

LATTES

Publications

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

- *"Automatic Design of Artificial Neural Networks for Gamma-Ray Detection"*, Filipe Assunção, João Correia, Rúben Conceição, Mário Pimenta, Bernardo Tomé, Nuno Lourenço, Penousal Machado, IEEE Access, Vol 7 (2019) 110531

1 International Conference Proceedings

- *"The sub-TeV transient Gamma-Ray sky: challenges and opportunities"*, G. La Mura, P. Assis, A. Blanco, R. Conceição, P. Fonte, L. Lopes, M. Pimenta, B. Tomé, C. Espírito Santo, L. Mendes, M. Ferreira, P. Abreu, P. Brogueira, L.F. Mendes, F. Barão, U. Barres de Almeida, R. Shellard, U. Giaccari, O. Lippmann, B. D'Ettorre Piazzoli, M. Doro, E. Prandini, C. Perennes, G. Matthiae, M. Tavani, R. Santonico, A. De Angelis, R.L. Coto, A. Chiavassa, J. Vicha, P. Travnicek and G. Di Sciascio, PoS(ICRC2019)721, proceedings of the ICRC2019, in Proceedings of Science https://pos.sissa.it/358

Presentations

2 Oral presentations in international conferences

- Giovanni La Mura: *"LATTES - a new detector concept to monitor VHE gamma-ray sources"*, 2019-01-25, eXtreme 19, Padova, Italy
- Giovanni La Mura: *"The Sub-TeV transient Gamma-Ray sky: challenges and opportunities"*, 2019-07-13, European Physical Society Conference on High Energy Physics 2019, Ghent, Belgium

1 Poster presentations in international conferences

- Ruben Conceição: *"The Sub-TeV transient Gamma-Ray sky: challenges and opportunities"*, 2019-07-30, 36th International Cosmic Ray Conference, Madison, WI, USA

1 Oral presentations in international meetings

- Bernardo Tomé: *"Wide field-of-view gamma-ray observatory in the Southern hemisphere"*, 2019-04-26, Second Joint Workshop IGFAE / LIP, Santiago de Compostela, Spain

1 Presentations in national conferences

- Ruben Conceição: *"The Southern Wide field-of-view Gamma-ray Observatory"*, 2019-09-13, XXIX Astronomy and Astrophysics National Meeting, IST, Lisboa, Portugal

2 Oral presentations in Advanced Training events

- Wagner Silva: *"Gamma-ray astrophysics with current and future detectors"*, 2019-09-04, LIP Summer Student Programme Final Workshop, LIP, Lisboa, Portugal
- Hugo Lóio: *"Development of novel reconstruction techniques for low-energy gamma-ray showers"*, 2019-09-05, LIP Summer Student Programme Final Workshop, LIP, Lisboa, Portugal

Theses

1 Master

- Ricardo Lordelo: *"Thermal Study of a Module for SWGO (Southern Hemisphere Wide field-of-view Gamma-ray Observatory)"*, 2018-09-13 / 2019-11-20, (finished)

[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 (92), Francisco Neves (70)[*], Helmut Wolters (20), José Pinto da Cunha (50), Salvatore Davide Porzio (15), 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 (100), João Fernando (30), Ricardo Cabrita (100), Susana Castanheira (30)

Total FTE:
11.8

Articles in international journals:
3 Direct contribution
2 Indirect contribution
Internal notes:
4 notes
International meetings:
2 Oral presentations
Collaboration meetings:
7 Oral presentations
Advanced Training Events:
1 Oral presentation
Seminars:
3 Seminars
2 Outreach seminars

[*] Co-PI
[+] Participation in the Competence Centre on Simulation and Big data within the project BigDataHEP included here

Executive summary

The LIP Dark Matter group joined the LUX experiment in 2010 and it is a founding member of the LUX-ZEPLIN (LZ) international collaboration. These two experiments aim to search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs).

LUX was decommissioned in the Autumn 2017. However the analysis of its data is still going on and it has produced a rich set of publications.

LUX-ZEPLIN (LZ) is a second-generation dark matter direct detection experiment. It moved underground, to the Sanford Underground Research Facility (SURF) in Lead, SD, USA, in Oct 2019. The complete assemblage and integration will last until middle Spring 2020. The first liquid xenon filling of the detector is expected to take place in the beginning of Summer 2020 followed by the LZ TPC commissioning and performance tuning. The first science run is expected to start by the end of 2020. There are no significant delays relative to the initial schedule.

In 2019, the dark matter LIP group has made crucial progress in the responsibilities assumed in LZ, namely the control system, the data quality monitor, data analysis tools at the level of pulse characterization and vertex reconstruction, background accounting and modeling. We were also the main group studying the sensitivity of the LZ detector to the neutrinoless double beta decay (0v2ß) of ^{136}Xe, a decay mode that has not yet been observed and whose detection is the second most important physics goal of LZ. We have also studied the sensitivity of LZ to the double beta decay of ^{134}Xe. Regarding LUX, we completed the data analysis regarding the search for the double capture (2DC) of ^{124}Xe and ^{126}Xe.

LIP members hold the following coordination positions in LUX-ZEPLIN in 2019:

- Alexandre Lindote - coordinator of the LZ Backgrounds Group
- Cláudio Silva - co-coordinator of the High Energy Analysis Group of LZ
- Vladimir Solovov - Co-coordinator of the LZ Control System

The LZ LIP team is represented by the PI of the project (I. Lopes) at the LZ Institution Board. Francisco Neves is co-PI of the project. Besides the project regarding the direct participation of LIP in LZ, there is also in the group the project led by Cláudio Silva on "Optical studies for performance and optimisation of particle physics detectors" IF/00877/2015/CP1311/CT0002.

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 LUX
Isabel Lopes	PTDC/FIS-PAR/28567/2017	239.807 €	2018-09-01 / 2021-08-31	Participation in LUX-ZEPLIN experiment: scientific and technical contributions

Total: 289.807 €

Dark Matter

Lines of work and team organization

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

- Data analysis tools for LZ, encompassing algorithms and techniques for pulse identification & characterization, detector related corrections and high-level analysis (Francisco Neves, Paulo Brás and Andrey Solovov).
- Physics Beyond Dark Matter search with LZ detector: neutrino physics studies, search for neutrinoless beta decay (0ν2β) in ^{136}Xe and ^{134}Xe, as well as other Xe rare decays such as double capture in ^{124}Xe e ^{126}Xe, with a strong focus on the use of machine learning algorithms for improving the signal to background discrimination (Alexandre Lindote, Cláudio Silva, Paulo Brás, Francisco Neves, Elias Asamar, Susana Castanheira, Fátima Alcaso).
- Position reconstruction methods (Guilherme Pereira, Vladimir Solovov).
- Modelling and GEANT4 based simulation of the radiation backgrounds in LZ (Alexandre Lindote, Cláudio Silva).
- Development of a database for accounting the radiation backgrounds in LZ (Helmut Wolters).
- Control system (Vladimir Solovov, Ricardo Cabrita and Guilherme Pereira).
- Development of the Data Quality Manager system for LZ (Francisco Neves, João Fernando).
- Modeling, simulation and measurement of the reflectivity of rough and diffuse surfaces (Cláudio Silva, Ricardo Cabrita, Davide Porzio, Vladimir Solovov).

Stated objectives for past year

1. **0ν2β in ^{136}Xe in LZ:**
   - Completion of the analysis to get the LZ sensitivity for 0ν2β and publish the results.
   - Test and benchmark the effciency of machine learning algorithms for the identiffication of 0ν2β events in LZ.
2. **Other Xe rare event searches with LZ:** To continue the LZ sensitivity study for the 2ν2β of ^{134}Xe.
3. **LZ Analysis Modules (LZap):**
   - Improve the current pulse classification and the matching algorithms for the LZ pulse analysis.
   - Publication of a paper on machine learning methods in dark matter direct detection experiments with dual-phase xenon technology.
   - Improve the position reconstruction module.
4. **LZ Backgrounds:**
   - Migration of the backgrounds repository from the Excel format to a database to be developed with additional functionalities**.**
   - Develop a radial model for the wall background and consequently update the current estimates of the background leakage from the walls in the fiducial region of the detector
5. **LZ DQM**: Integrate the DQM with the Event Builder and other UG online infrastructures. Develop an improved set of analysis macros using data from the MDC3.
6. **PTFE optical properties:** Continue the identification and characterization of the PTFE fluorescence when irradiated with xenon scintillation light at low temperature.
7. **LZ control System (CS)**: i) Continue with GUI development for critical subsystems and Kr removal; ii) Implementation of automation scripts for the updated module; iii) Implementation of the interface with Run Control; iv) Automation Test with Simulators; v) Checkout and validation of CS with Hardware; vi) Participation in deployment of Ignition infrastructure underground.
8. To complete the LUX data analysis regarding the search of double electron capture in ^{124}Xe.

Achievements and responsibilities during the past year

I - LZ Analysis Modules (LZap)

1. The Pulse Matching algorithm was improved. A new approach allows to cope with the complexity of the pulses besides having the required accuracy and speed.
2. **Pulse Finder**: The developed algorithm is based on multi-scale feature detection techniques frequently used in image processing and Machine Learning. The implemented module was refined and tested against the various releases of simulated data and proved to be robust enough to use in all 3 LZ detectors (i.e. TPC, Outer and Skin detectors).
3. **Pulse Classiﬁcation**: Concerning the pulse classifier module LZap, the work was centred on exploring the requirements and performance of dedicated machine-learning (ML) algorithms for pulse classification. The study covers artificial neural networks, convolutional neural networks, random forests and clustering algorithms, using both supervised, semi- and fully unsupervised learning techniques.
4. **Position reconstruction:** The S2 position reconstruction code based on Mercury algorithm developed in LIP-Coimbra was updated with the following enhancements: i) Increased energy range; ii) New cost functions for weak signals (maximum likelihood with Poisson and Hessian statistical models - to handle weak events and double photoelectron production, respectively), iii) Updates to maintain compatibility with the main LZAP code; iv) Provision for non-functional PMTs; iv) Additional parameters returned: corrected S2 area, goodness-of-fit, covariance matrix and reconstruction status.

II - Physics beyond the dark matter search

- The study of the LZ sensitivity for the 0v2ß of ^{136}Xe was completed. Based on a Profile Likelihood Ratio (PLR) analysis, it was concluded that upon its 1000 day run, LZ can reach a ^{136}Xe neutrinoless double beta decay half-life sensitivity of 1.06×10^{26} years, a result which is competitive with the current best limits for this decay, even with this classical analysis. A paper with this result was submitted to PRC. P. Brás from our team is one of the two main authors.
- The LZ sensitivity to the ^{134}Xe decay via the standard 2v2ß mode and the beyond standard model 0v2ß process has been completed. A paper was written and it is currently under internal review. Elias Asamar from LIP did the analysis, wrote the paper and he is the corresponding author.
- The investigation of machine learning techniques to optimize the track reconstruction for improving the 0v2ß decay discrimination has attained very promising results.
- The analysis of LUX data to search for the double capture of ^{124}Xe and ^{126}Xe were carried out and completed. A paper was submitted to Phys. Rev. C. Alexandre Lindote is one of the corresponding author.

III - LZ Backgrounds

- Alexandre Lindote from LIP continued to coordinate the Background Simulations group, which is responsible for making accurate estimates of the various background sources for WIMP and other physics searches.
- The background database, for which LIP has fully responsible, is almost completed.
- The preliminary version of the model to describe the backgrounds from the inner walls is ongoing.

IV - GPU based online data analysis framework for LZ (DQM)

- The design of the DQM framework has been completed.
- The DPE - the Data Processing Enviroment, DPE, - was designed taking advantage of GPUs as well as of modern multi-core processors.
- The DPE's GUI was implemented based on FLASK and JSROOT.
- Two analysis modules of the data processing implemented in GPUs are already completed

V - LZ control System (CS):

- The CS has been installed underground and being integrated with LZ subsystems, the pace of this process is being dictated by readiness of the subsystems.
- The test of CS with the hardware is almost complete (10000 channels have already been tested); the completion depends on readiness of the subsystems.
- As planned, we implemented a specialized GUI and tested it with hardware simulators as at that point most of the hardware was not ready.
- The Interfaces with non-critical subsystems, such as the source deployment, water tank and TPC LED Calibration System was developed.
- Interfaces with the experiment infrastructure units (Run control, DAQ and Data Quality Control) were defined.

Lines of work and objectives for next year

The main lines of work and objectives of the Dark Matter Group are the following:

I - LZ Analysis Modules (LZap)

1. The pulse analysis modules will be tuned against real data once the detector starts to be tested filled with liquid xenon, which is expected to happen in early summer.
2. The position reconstruction algorithm will be used/assessed for:
   - Reconstruction of the real detector response by Mercury algorithm.
   - Reducing the background event leakage into fiducial volume in the presence of afterpulsing and double phe production
   - Mitigation of failed PMT (increasingly important for large PMT arrays and long run periods)
   - Providing better estimate for corrected S2 area by including information from the bottom PMT array.

II- Physics beyond the dark matter search

1. For each Xe rare decays we have investigated various discriminator variables (e.g. S2/S1 ratio, S1 and S2 pulse shapes, position reconstruction S2 maps) that can be used to probe their topology using machine learning algorithms specialized in pattern recognition and anomaly detection. The goal is to improve efficiency in background discrimination and enhance the experimental sensitivity. Background and signal models incorporating information from the most relevant variables will then be used in a profile likelihood analysis to optimize LZ sensitivity to the various decays.
2. Extend the analysis that led to the determination of the limit of the half-life of the DEC of ^{124}Xe using the data from LUX to the determination of LZ sensitivity to this decay.

III - LZ Backgrounds

1. The database for accounting of the LZ backgrounds will be completed . A graphical user interface will allow users to generate summary tables and reports and test contamination scenarios for specific components.
2. We will have a preliminary version of a model to describe the background generated by the decay of daughters of ^{222}Rn (namely from 210Pb onwards) plated in the PTFE walls of the detector.

IV - Data Quality Manager (DQM)

During 2020 the DQM will be commissioned onsite alongside with the detector and all other subsystems. The expected road map is:

1. During the 1st trimester, the DQM will be installed at SURF and integrated with the LZ Run Control (RC), Event Builder (EB), Slow Control (SC) and the Physics REadiness Monitor (PREM) sub-systems.
2. During the same period, and in coordination with the responsible from the LZ Liquid Xenon Time Projection Chamber (TPC), LXe Skin (Skin) and Outer Gadolinium-loaded (OD) veto detectors, we will determine the relevant quantities to be monitored for each of the detectors at the various working conditions and the respective alarm levels.
3. During the 2nd trimester, the DQM must have all the monitors ready for:
    1. The 1st PMT tests with LEDs both in warm and cold gas;
    2. The ramping of the anode, gate and cathode HV grids in gas. This step is critical and all monitors will be specialized to the early detection of electrical discharges with potential to damage the detector;
4. By the start of the 2nd semester, the LZ TPC will be cooled down and filled with LXe. During this stage, the DQM monitors will be again specialized to monitor the health of the PMTs, the LXe purity evolution and the HV ramping to its nominal values.

V - LZ Control System

The workflow of the circulation tests planned from the first trimester of 2020 is highly dependent on the control system infrastructure. The integration with the subsystems and subsequent commissioning will require considerable attention from the Coimbra developers with significant on-site presence. The Ignition development will continue with a focus on the infrastructure required for commissioning, including dedicated GUI panels and facilities for managing alarms and interlocks. We will continue integration of slow control with the components of the experiment infrastructure (Run control, DAQ, DQM and databases). Also, the interface by which slow control will be able to provide relevant historical data to data analysis is going to be created.

VI - Optical studies of re ecting surfaces

For the year 2020, we plan to perform the following tasks:

1. Measurement and characterization of the roughness profile of the internal surfaces used in LZ using an atomic force microscope. We plan to measure both the height distribution and correlation distribution of the surface roughness;
2. Implementation of a new reflectance model in the LZ simulation tools. This new reflectance model will make use of the roughness measurements performed in 1);
3. Development of a model to describe the radial distribution of the background events in the walls of the LZ detector and characterization of the systematic and statistical uncertainties of the position reconstruction using the wall events. The wall model will also make use of the roughness measurements performed in 1) to estimate the fraction of energy deposited in the PTFE walls for the ^{210}Pb decay;
4. Measurement of the luminescence of the PTFE used in LZ. We plan to characterize the luminescence emitted by the PTFE in the timescale of some μs until several hours;
5. Measurement of the effect of a liquid interface in the diffuse reflectance using a total integrating sphere for different liquids, wavelengths and materials.

This work will be carried out in the framework of the project IF/00877/2015/CP1311/CT0002 whose PI is Cláudio Silva.

Medium-term (3-5 years) prospects

The first science run will start by the end of 2020 and it is expected to last for 6 months (170 live days). This will be followed by three months for calibrations and maintenance. The second science run will last for about 450 days. The third science run is expected to extend from the beginning of 2023 up to middle 2025. Overall, ~1000 live-days of science run will be accumulated. During these five years, our research work strongly depends on whether we will detect WIMPs or not. Nevertheless, we can foresee that our activity will proceed along three main directions:

1. To exploit the data acquired by LZ, in particular for the WIMP search using a Profile Likelihood Ratio (PLR) analysis and the neutrinoless beta decay 0ν2ß in ^{136}Xe. 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 in ^{134}Xe, as well as the 2ν2EC in ^{124}Xe.
2. Together with teams of the UK, we will work on the proof of existence of the Migdal effect in gas and liquid xenon. This effect predicts a small but non-zero probability for atomic ionisation if the duration of the nuclear collision is much shorter than the electronic orbital periods. Exploring this effect would allow lowering the LZ threshold significantly and therefore to extend the search of DM particles to much lower mass.
3. We will be strongly involved in the plans towards the construction of a G3 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 XnT perform.

The group will continue its commitments regarding the Control System and DQM maintenance, as well as the participation in the operation activities. We will also keep responsible for any assistance or upgrade regarding the analysis tools that we have developed (i.e., the pulse analysis and position reconstruction modules).

SWOT analysis

Strengths

The group is a well-established and highly considered member of the LUX and LZ Collaborations. Besides the long experience in WIMP search experiments, as well as a worldwide acknowledged expertise in liquid xenon detectors and their physics aspects, the group also has strong scientific and technical expertise in control and automation, position reconstruction methods, Monte-Carlo simulation of detectors and associated physical processes, background analysis and simulation in rare event particle experiments, analysis techniques of very low amplitude signals, data analysis of WIMP search experiments, optical measurements and photodetectors, data processing frameworks. With such wide range of solid competences and its size, the group can have a strong participation with relevant impact in dark matter experiments of large scale such as LZ.

The group has a laboratory in Coimbra equipped to purify and liquefy xenon, and to operate liquid xenon detectors.

Weaknesses

Currently we have only two PhD students (one about to get the degree).

There is shortage of several pieces of equipment and others are obsolete. The funding is very limited, which does not allow to buy equipment.

Opportunities

LZ is the most competitive WIMP direct detection experiment in the world, with a high potential of detecting WIMPs. To participate in such experiment is by itself a huge opportunity with several components from which we highlight two: 1) to use and extend our areas of expertise; 2) to hire researchers and attract PhD students. In 2019, we have attracted 4 additional Master students to carry out their research projects in the framework of the project.

Threats

The project was funded in the framework of 2017 PTDC Call. However the funding is very reduced and insufficient to run the project. Although the project was fully funded (240 k€ for 3 years), after subtracting the compulsory contract of a researcher and the overheads, we have only 26k€/year for all the expenses, which is obviously insufficient. The funding structure in Portugal continues to be unstable and poorly adjusted to large continuing projects. The limited funding or the frequent time gaps between consecutive calls for proposals are a permanent threat for the project.

Dark Matter

Publications

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

- *"Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment"*, D.S. Akerib et al., Accepted for publication in PRD
- *"Results of a search for sub-GeV dark matter using 2013 LUX data"*, D. Akerib et al , Phys. Rev. Lett. 122, 131301, 2019
- *"Improved measurements of the β -decay response of liquid xenon with the LUX detector"*, D Akerib et al, Phys. Rev. D 100, 022002, 2019

4 Collaboration notes with internal referee

- *"DEC analysis in Run04"*, A. Lindote, LUX Internal Note LuxDB0548
- *"LZ Background Model Summary"*, A. Lindote, P. Sorensen et al, LZ internal note LzDB00145
- *"DEC analysis in the full LUX exposure"*, A. Lindote, LUX internal note LuxDB0549
- *"First estimate of the 124Xe 2v2K signal in LZ"*, A. Lindote, LZ internal note LzDB00156

Presentations

2 Oral presentations in international meetings

- Elias Asamar: *"Status of the LZ experiment"*, 2019-09-25, 16th MultiDark Consolider Workshop, La Rábida, Huelva, Espanha
- Paulo Brás: *"Machine learning in LZ"*, 2019-1-11, 1st BigDataHEP meeting , Coimbra

1 Oral presentations in Advanced Training **events**

- Alexandre Lindote: *"Dark Matter: from the galaxies to deep mines"*, 2019-02-11, 4th Lisbon Mini-School on Particle and Astroparticle Physics, Costa da Caparica

3 Seminars

- Elias Asamar: *"The search for dark matter particles with mass below the GeV scale"*, 2019-03-20, Department of Physics, University of Coimbra
- Isabel Lopes: *"Searching for Dark Matter with LUX and LUX-ZEPLIN "*, 2019-04-17, University of Thessaloniki, Greece
- Francisco Neves: *"Looking for the dark side of the Universe"*, 2019-12-02, Seminários de Engenharia Física, Departamento de Física, UC, Coimbra

2 Outreach seminars

- Guilherme Pereira: *"LZ - Lux Zeplin. A search for Dark Matter"*, 2019-02-07, 20ª JORTEC da FCT - UNL
- Paulo Brás: *"Dark Matter @LIP"*, 2019-11-19, Departamento de Física da Universidade de Coimbra

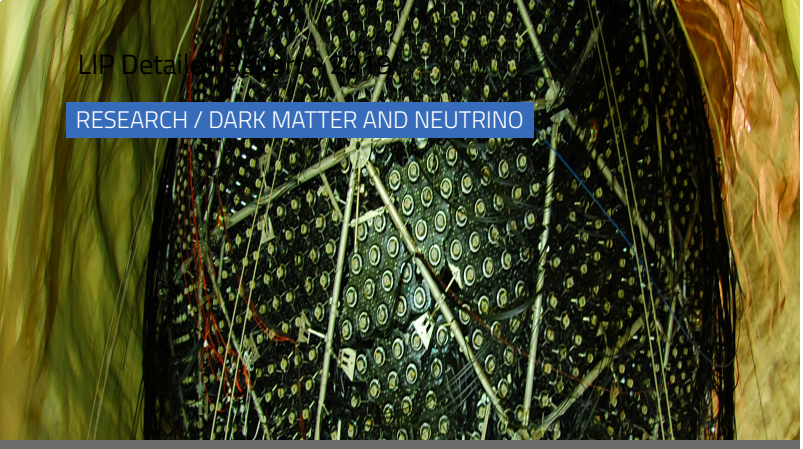
Theses

2 PhD

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

- 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)
- Jacinto Fonseca: *"Detection of Magnetic Inelastic Dark Matter"*, 2017-10-02 , (ongoing)
- Susana Castanheira: *"Discovery potential of the LZ detector to the double electron capture decay of Xe124"*, 2019-09-24 , (ongoing)
- João Fernando: *"Development of the Online Data Quality Monitor for LZ"*, 2019-09-09 , (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)

8 ***Researcher(s):***
Amélia Maio (15), Fernando Barão (25), Francisco Neves (5), Nuno Barros (67), Pedro Jorge (7), Sofia Andringa (60) [*], Valentina Lozza (93), Vladimir Solovov (8)

3 ***PhD Student(s):***
Ana Sofia Inácio (100), Matthew Cox (13), Stefan Nae (75)

1 ***Master Student(s):***
Glória Pereira (83)

5 ***Trainee(s):***
António Maschio, João Carlos Antunes, Leonardo Oliveira, Miguel Avillez, Samuel Magalhães

1 ***External collaborator(s):***
Gersende Prior

Total FTE:
6.5

(*) Co-PI

Articles in international journals:
3 Direct contribution
3 Indirect contribution
Internal notes:
3 Notes
International conferences:
1 Poster
3 Proceedings
International meetings:
1 Oral presentation
Collaboration meetings:
54 Oral presentations
Advanced Training Events:
3 Oral presentations
Seminars:
2 Seminars
2 Outreach seminars
Completed theses:
1 Master

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 has started and is expected to be completed in 2020, and so the group's efforts have shifted from water phase to scintillator phase data analysis.

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 operation/data analysis of the ProtoDUNE detectors at CERN.

There is a strong (but not complete) overlap between the SNO+ and DUNE teams, and we pursue a common strategy of balancing data analysis of a current experiment (SNO+) with development and R&D for a future one (DUNE).

Sources of funding

PI	Code	Amount	Dates	Description
Valentina Lozza	IF/00248/2015/CP 1311/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: 184.000 €

Neutrino

Lines of work and team organization

SNO+

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 stability and spatial distribution 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.

DUNE

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 a Los Alamos (LANL) experiment for 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-SP DAQ trigger electronics
  - ProtoDUNE-DP installation, commissioning and purity monitor analysis
  - ProtoDUNE data analysis: cosmics and beam data, neutron response

List of internal SNO+ leadership responsibilities taken by group members: 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). In addition, we are responsible for software documentation, within the software validation group (ASI) and the data processing group (MC), and for overseeing the SNO+ run selection database (SN).

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

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

In addition, the group also contributes to Particle Physics Outreach activities. SA is the group's contact person in this area.

Stated objectives for past year

SNO

- Analysis of the HeP solar neutrino flux with the full SNO data set.

SNO+

Calibrations

- Deliver the last URM
- Complete the optical and neutron calibration analyses in water
- Finalize the plans for gamma sources.

Analysis

- Automate the data quality/run selection framework,
- Search for antineutrino and alpha-n background events in water,
- Improve the external backgrounds constraints.
- Measure the scintillator radiopurity while filling.
- Prepare the antineutrino, the alpha-n and the Be7 solar neutrino analyses in scintillator
- Continue sensitivity studies for the DBD phase
- Study muon-induced background.

DUNE

Far detector calibrations

- Laser system:
  - Estimate and optimize the precision and coverage
  - Interface the laser and DAQ.
- Pulsed neutron system:
  - Optimize source, and its position
  - Measure the neutron transmission in Argon.

ProtoDUNE

- Analyse cosmic muon data and search for neutron signals
- Contribute to the trigger/DAQ of the SP detector
- Design the calibration systems prototypes to be tested in 2021.

Achievements and responsibilities during the past year

SNO

The analysis on the search for the hep solar neutrino flux is now completed, and a paper will soon be submitted.

SNO+

Most of the 2019 SNO+ goals have been achieved. The LIP control room was successfully used to carry out most of our shifts remotely.

Calibrations

The 2nd calibration source deployment device arrived at SNOLAB, while the 1st has been sent underground, thanks to the long term stay of ASI (and SN in 2018) at site. The water phase neutron calibration data analysis resulted in the measurement of the neutron proton capture cross-section with high sensitivity, to be published soon. The water phase optical calibration analysis was completed, providing an improved tuning of the simulation to data. The low energy gamma source calibration plan has been delivered and the source bought and tested.

We contributed to the automation of the data quality/run selection framework, that was used for the final processing of the water phase data.

Water Phase Analysis

With regular updates on the water radiopurity, we provided operational feedback to purification and cover gas activities. We continued to coordinate the backgrounds group focusing on the low background period analysis, which will be used to improve the sensitivity to the nucleon decay search. We are testing the water phase antineutrino analyses, including a better evaluation of alpha-n backgrounds.

Scintillator Phase Preparation

Scintillator fill started in 2019. We coordinate the analyses of the scintillator optical and radiopurity properties with SNO+ data, providing weekly feedback to scintillator purification and filling operations. One of the analyses focused on the ^{214}Bi-^{214}Po chain, allowing the test of coincidence algorithms aimed at anti-neutrino signals.

DUNE

The activities in DUNE have quickly ramped up in 2019, with a clear focus on the design of the far detector calibration systems and on operations, commissioning and analysis of the ProtoDUNE (SP and DP) prototypes at CERN.

DUNE far detector (FD) calibrations

We focused on the two baseline calibration systems for the FD -- the ionization laser and the pulsed neutron source – and the interface of both with the DAQ system. We contributed as co-editors (JM) and co-authors (JM, SA) of the calibration chapters of the Technical Design Report, now submitted for publication.

The ionization laser system aims at measuring distortions of the drift velocity and the electron lifetime, with UV laser tracks inserted into the cryostat via optical feedthroughs. In 2019 we established the coverage requirements, optimized the design of the steerable feedthrough and proposed an independent beam location system.

Knowledge of the neutron transmission in argon close to an expected anti-resonance is crucial for estimation of the neutron backgrounds and the feasibility of the Pulsed Neutron Source calibration. We participated in the data taking and analysis of an experiment at LANL (ARTIE) aimed at improving the sensitivity to very high transmissions by employing a long liquid target instead of gas. The detailed analysis is ongoing.

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). In 2019 the Calibration Consortium was merged with part of the Cryogenic Instrumentation and Slow Controls Consortium.

ProtoDUNE

We have performed maintenance and operation of the trigger system for ProtoDUNE-SP, being responsible for the design of new trigger configurations, maintenance of the firmware and software, and support to the data analysis groups.

We have participated in the installation and commissioning of the ProtoDUNE-DP detector at CERN, and on the readout of the slow control data from all the cryogenic instrumentation sensors. We operated and analysed the data from the LAr purity monitors. These are used to check the oxygen contamination, an important limiting factor to the performance of large liquid argon (LAr) TPC detectors.

We have also carried out a modelization study of the space charge effect (positive ion accumulation) and its impact on straight track position distortions.

Lines of work and objectives for next year

SNO+

In SNO+, with most hardware and service tasks completed, this year we will mainly focus on data analyses. In the next two years we expect to cover the three phases: filling, full unloaded scintillator and initial Te-loading. Additionally, we will continue to analyze the very low background water data taken since October 2018.

Following the work started in the past years, in 2020 we foresee to lead several water phase physics publications, as well as scintillator phase analyses.

The specific planned activities are the following.

Calibrations and Background

- Approve the design of interface equipment necessary for the scintillator phase calibrations.
- Propose the run plans and participate in optical, neutron and gamma calibrations in the scintillator phase.
- Provide the optical parameters for pure scintillator from the analysis of the 2020 calibration campaigns.
- Provide a continuous monitor of the purity, optical quality (light yield, quenching) of the scintillator during the filling phase. Including detector stability and uniformity response and identification of any unknown contamination in the region of interest of DBD searches.

Water Phase Analysis

- Finalize and submit for publication the paper on neutron-proton capture in water.
- Apply the method developed for the antineutrino analysis to the low background water data, to extract the amount of alpha-n events (background to the antineutrino signal) due to Polonium leaching from the Acrylic Vessel. Prepare the corresponding paper.
- Finalize the analysis of the low background data (2018-2019) to improve the measurement of the external backgrounds (important constraint for the DBD phase) and prepare the corresponding paper.
- Coordinate ongoing analyses of the water dataset toward completion and publication of associated papers, namely an improvement on the already published nucleon decay limits.

Scintillator Phase Analysis

- Deploy the antineutrino search analysis, focusing on reactor oscillation physics. 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.
- Complete the analysis tools for an analysis of the ^{7}Be solar neutrino signal in SNO+ and apply to data. Since this component has a high flux, a publication-quality measurement could be done with even a short pure scintillator phase.
- Study muon-induced correlated events in partial fill, such as the decay of cosmogenic ^{11}C and ^{10}C, an important background to some solar and DBD analyses.
- Continue the preparatory work for the double-beta decay phase with sensitivities study as a function of cocktail purity, mitigation strategies, and optics effects.

DUNE

ProtoDUNE

ProtoDUNE-II will be installed in Fall 2021 and is intended to test all detector components of the final configuration of the first DUNE cryostat. In 2020 we will mostly focus on preparing the calibration system hardware and their interface to timing, slow control and DAQ.

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 of the ionisation laser calibration system, focusing on improving the coverage – with an additional third degree of freedom with respect to the MicroBoone design – and precision of pointing at long distances, all crucial for a very large detector such as DUNE. In collaboration with the LANL group, we will contribute to the construction of the first prototypes to be installed at ProtoDUNE in 2021, especially the mechanical flanges and a mirror-based location system.

We have proposed an implementation for the interface between DAQ and the calibration systems, consisting of an electronics board with an FPGA and a CPU, permitting to translate DAQ commands to the calibration system, and populating the slow control database with relevant monitoring quantities.

The development on calibration hardware will be accompanied by software implementing the automatic procedures to perform the complete scan of the active volume, interfaced with the Run Control and DAQ, and ensuring mechanical reproducibility of the 3D scan. The software to process the laser data in order to characterize and normalize the response of the detector in 3D will be developed in conjunction with the ProtoDUNE data analysis software framework.

We will complete the analysis of ARTIE data and check its effects on background neutrons and the Pulsed Neutron Source. A first test beam with neutrons – with a similar neutron generator, but no energy filter, may occur already in 2020, giving a good data set to train neutron capture identification in the presence of large backgrounds.

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: partial scintillator fill and pure unloaded scintillator in 2020, and Te-loaded scintillator from 2021 onwards. 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 DUNE participation, 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 liquid argon 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

The very “top-heavy” structure, with eight researchers and only three PhD students, 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's 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.

Neutrino

Publications

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

- *"Measurement of the 8B solar neutrino flux in SNO+ with very low backgrounds"*, M. Anderson et al. (SNO+ Collaboration), Phys. Rev. D 99, 012012 (2019)
- *"Search for invisible modes of nucleon decay in water with the SNO+ detector"*, SNO Collaboration, Phys. Rev. D 99, 032008
- *"Constraints on Neutrino Lifetime from the Sudbury Neutrino Observatory"*, B. Aharmim et al. (SNO Collaboration) Barros, Maneira, Prior, Phys. Rev. D 99, 032013

3 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
- *"SNO+ present results and prospects"*, S. Andringa on behalf of the SNO+ Collaboration, Proceedings of BEACH 2018 - XIII International Conference on Beauty, Charm and Hyperon Hadrons, (June 2018, Peniche, Portugal), Conf. Series1137 (2019) 012053
- *"The SNO+ Experiment"*, V. Lozza for the SNO+ Collaboration, Proceedings of the 5th International Solar Neutrino Conference, pp. 313-328 (2019)

3 Internal notes

- *"AmBe Statistical Analysis Description"*, S. Andringa, SNO+ Internal Note 5537
- *"Status of background in water phase - running updates"*, V. Lozza, SNO+ Internal Note 5372
- *"Cesium-137 calibration proposal and review package"*, V. Lozza, SNO+ Internal Note 6047

Presentations

1 Poster presentations in international conferences

- Valentina Lozza: *"Backgrounds Analysis for the SNO+ Experiment"*, 2019-09-10, TAUP 2019 - Topics in Astroparticle and Undeground Physics, Toyama, Japan

1 Oral presentations in international meetings

- Valentina Lozza: *"Alpha-n backgrounds in SNO+"*, 2019-11-21, (alpha,n) yield in low background experiments, Madrid, Spain

3 Oral presentations in Advanced Training **events**

- José Maneira: *"Understanding the Universe with Neutrinos and Astroparticles"*, 2019-02-11, 4th Lisbon mini-school on Particle and Astroparticle Physics, Costa da Caparica
- Ana Sofia Inácio: *"Measurement of Te130 Two-Neutrino Double Beta Decay Half-Life with the SNO+ Experiment"*, 2019-05-30, Joint 9th IDPASC SCHOOL and XXXI INTERNATIONAL SEMINAR of NUCLEAR and SUBNUCLEAR PHYSICS , Otranto, Italy
- Ana Sofia Inácio: *"Measurement of Te130 Two-Neutrino Double Beta Decay Half-life with the SNO+ Experiment"*, 2019-07-02, IDPASC and LIP PhD student workshop, Braga

2 Seminars

- José Maneira: *"DUNE: Probing the origin of matter with neutrino oscillations"*, 2019-07-04, Colóquio de Física da Universidade do Minho, Braga
- Ana Sofia Inácio: *"The Optical Calibration of SNO+ with the Laserball"*, 2019-11-28, Seminar at Laurentian University, Sudbury, Canada

2 Outreach seminars

- José Maneira: *"O que os neutrinos nos podem dizer sobre o Universo"*, 2019-03-12, , Colégio Pedro Arrupe, Lisboa
- José Maneira: *"O que os neutrinos nos podem dizer sobre o Universo"*, 2019-05-08, Dia Aberto da FCUL, FCUL Open Day

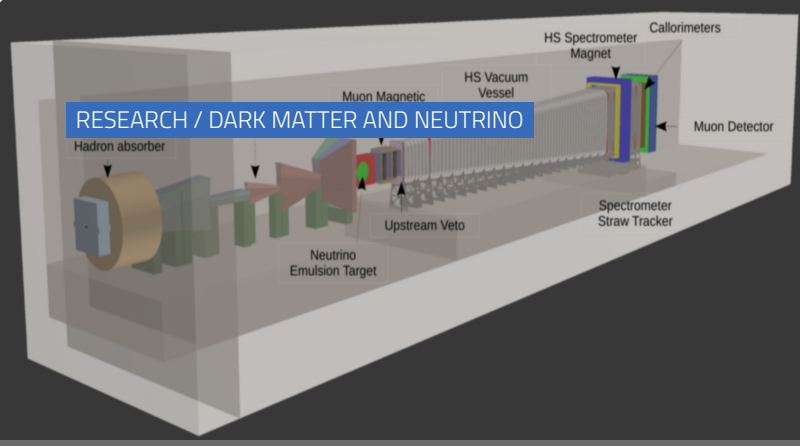
Theses

3 PhD

- Stefan Nae: *"Anti-Neutrino physics in SNO+"*, 2016-01-01 , (ongoing)
- Ana Sofia Inácio: *"Measurement of the 130 Te Two-Neutrino Double Beta Decay Half-life with the SNO+ Experiment"*, 2018-03-01 , (ongoing)
- Matthew Cox: *"Background characterisation for water and scintillator phases of SNO+"*, 2018-10-01 , (ongoing)

1 Master

- Glória Pereira: *"The impact of electric field distortion on CP violation studies: study of space charge effects on ProtoDUNE"*, 2018-10-03 / 2019-10-30, (finished)



SHIP

Search for Hidden Particles

Principal Investigator:
Celso Franco (30)

5 ***Researcher(s):***
Alberto Blanco (40), Nuno Leonardo (6), Paula Bordalo (10), Paulo Fonte (35), Sérgio Ramos (10)

6 ***Technician(s):***
João Saraiva (30), Luís Lopes (15), Nuno Carolino (15), Nuno Filipe Silva Dias (15), Orlando Cunha (15), Rui Alves (20)

1 ***Master Student(s):***
Guilherme Soares (75)

2 ***Undergraduate Student(s):***
Beatriz Araújo, Mariana Pinto

Total FTE:
3.2

Articles in international journals:
2 Indirect contribution
Collaboration meetings:
3 Oral presentations

Executive summary

The SHiP experiment is being designed to search for extremely feebly interacting, relatively light and long-lived particles, at the intensity frontier. The experiment will be located in a new beam dump facility at CERN where it will use the high-intensity beam of 400 GeV/c protons from the SPS accelerator. Presently SHiP is a CERN recognized collaboration of about 250 Physicists from 54 institutes and 18 countries. An approval to proceed with a 3-year TDR phase is expected within the next 12 months, with the aim of starting to take data in 2028. The main goal of SHiP is to explore the so-called Hidden Sector (HS) of particle physics in a region of phase space that is not accessible to the LHC experiments.

The discovery of the Higgs boson at the LHC made the Standard Model (SM) of elementary particles complete. Nevertheless we are certain that the SM does not represent the full picture of the quantum world. For instance, it cannot explain the existence of neutrino masses, dark matter, matter-antimatter asymmetry and inflation. The fact that no convincing signs of new particles have been found so far suggests that they are either heavier than the reach of present days accelerators or that they interact very weakly. SHiP will address the above mentioned topics by searching for long-lived particles with masses ranging from hundreds of MeV/c² to few GeV/c². In addition to that, the physics program of SHiP also encompasses a unique study of tau neutrino physics.

The LIP group is directly involved in the optimization of the selection of several Hidden Particles (HP): Heavy Neutral Leptons (HNLs), the hypothetical right-handed neutrinos; Dark Photons; Axion-Like Particles and sgoldstinos. 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. The SM decays of two of the HNLs can be detected at SHiP. Concerning the Dark Photons 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 supersymmetry breaking scale up to 10^5 GeV by detecting their SM decays.

Currentely our group is responsible for a 2x10 m² Veto Detector, based on RPC technology, whose purpose is to veto events originating in neutrino or muon DIS. In addition, the group is also competing for the construction of a 50 m² Timing Detector with the aim of suppressing the muon combinatorial background. Both detectors are crucial to ensure a nearly zero background environment for the experiment. Machine learning algorithms are also being developed at LIP to ensure not only the desired background level - by combining kinematic properties with timing information - but also to obtain automatic event probabilities for the above mentioned HP.

Sources of funding

PI	Code	Amount	Dates	Description
Alberto Blanco	CERN/FIS-PAR/0030/2017	10.000 €	2018-01-01 / 2019-12-31	Search for Hidden Particles

Total: 10.000 €

SHiP

Lines of work and team organization

The line of work of the LIP group is subdivided in two tasks:

1) Prototyping of Timing and Veto RPC detectors, development of a mechanical structure for the Timing Detector, integration of a front end SAMPIC board and development of a re-circulation/purification system for the RPC modules

2) Optimization of the selection efficiency of Hidden Particles (HP) using machine learning algorithms

This project involves a close collaboration between the Lisbon and Coimbra poles of LIP. The task 1) is hardware oriented and will be performed by the Coimbra members of the group: Alberto Blanco, Luis Lopes and João Saraiva. The task 2) involves contributions to the development of simulations of several HP and also of all conceivable background processes, the simulation and optimisation of the properties of the Timing and Veto Detectors and the development of machine learning algorithms with the goal of using both kinematic and timing properties to maximize the selection efficiency of HP with a nearly 100% purity. This task will be performed by the Lisbon members of the team: Celso Franco, Nuno Leonardo, Guilherme Soares, Beatriz Araújo, Paula bordalo and Sérgio Ramos. Part of this work will be the subject of a master thesis in 2020.

Stated objectives for past year

- Finalize the analysis of the 2018 test beam data, present results to the collaboration and prepare a paper for publication.
- Finalize the implementation in the official software, FairShip, of the Timing Detector based on RPCs and evaluate its impact on the various physics channels.
- Elaborate a preliminary mechanical implementation of the placement of the different modules in order to cover the 50 m² of the timing detector.
- Recently, the collaboration also proposed to our group the construction of a smaller RPC (~ 10 m²) to be placed at the end of the neutrino detector, the timing detector of the neutrino spectrometer. The group is going to evaluate the requirements and a possible solution will be presented to the collaboration.
- Start a close collaboration with the SHiP neutrino group with the goal of optimizing the neutrino spectrometer for the various physics channels. Relevant contributions can be provided with the help of machine learning techniques.

Achievements and responsibilities during the past year

All stated objectives for the year of 2019 were accomplished. The group started a close collaboration with the SHiP neutrino group to evaluate the impact of introducing a RPC Veto Detector (VD) of 10 m² at the end of the muon system of the neutrino detector. The VD preceds the entrance of the SHiP decay vessel, where the Hidden Particles (HP) are expected to decay, and serves the purpose of vetoing events produced in the muon system by neutrino or muon DIS. These events are dangerous as they may produce neutral particles that mimic HP decays inside the decay vessel. A preliminary optimisation of the VD was performed by our group and the detector is already implemented in the official simulation software of SHiP (FairShip): two double layers of 5 RPC modules of 223 cm (x) X 105 cm (y) X 1.35 cm (z). The modules of the first layer contain 32 horizontal strips, to measure the time of flight of particles, whereas the second layer contain modules of 64 vertical strips to measure also position. The two systems push the detection efficiency close to 100% and provide a timing resolution of 300 ps.

Concerning the 50 m² Timing Detector (TD), a preliminary implementation in a development branch of FairShiP is already available. The detector consists of 35 RPC modules of 160 cm (y) X 120 cm (x) X 2.51 cm (z), containing 32 vertical strips, distributed in 4 layers. The time resolution, tested with a first prototype at CERN, is of 54 ps with an average efficiency above 98%. Preliminary tests about the impact of its material budget in the reconstruction of HP were also carried out. In particular, it was confirmed that the detector does not degrade the reconstruction efficiency of double photons coming from an ALP decay (compared to the competition). However, more detailed studies are required concerning the capability of the present RPC design for a simultaneous detection of few particles in the same module. Therefore, the inclusion of the TD in the official version of FairShip is still pending final optimisation. Concerning the mechanical structure, a very preliminary version of it was developed at Coimbra and already presented to the collaboration.

In 2019 the group managed to attract 3 researchers, 2 undergraduate students and 1 master student. The latter is collaborating in the development of machine learning algorithms with the purpose of maximizing the selection efficiency of HP compared to a standard cuts analysis. By combining in a multidimensional way the kinematic properties of both signal and background events together with the timing information, provided by the RPC detectors, one expects to improve the efficiency of the HP selection while keeping the purity of the samples at nearly 100%. Since SHiP is a discovery experiment, this work is extremely important to enable the accumulation of rare events that will allow reconstruction of the HP masses.

Lines of work and objectives for next year

For 2020, the plan is the following:

- Build and test (with a pion beam at CERN) two full size RPC modules for the Veto Detector (VD): one module containing 3 glasses of 223 cm (x) X 105 cm (y) X 2 mm (z) and 32 horizontal readout strips, followed by another replica of the module containing 64 vertical readout strips
- Test the use of the default SAMPIC board of SHiP to readout the signals provided by the RPCs very front end electronics with picosecond timing accuracy
- Continue the development of a mechanical implementation for the placement of the different RPC modules covering the 50 m² of the Timing Detector (TD).
- Evaluate the need to move from 2 m² TD modules with 32 readout strips to TD modules of much smaller size containing a single readout strip. The design must allow a measurement of the time of flight of simultaneous particles with a time resolution below 60 ps and an efficiency above 98%. Dedicated simulations of most important hidden particles will be used to optimize the transverse area of the modules and also to minimize the impact of its material budget in the subsequent electromagnetic calorimiter.
- Optimize the properties of the VD with the goal of vetoing all standard model particles entering the SHiP decay vessel. A dedicated simulation of the expected muon flux will be developed in order to make sure that the VD can handle the charged particle rate. If needed, protective measures will be included in the design (iron slabs) to reduce the rate below 100 Hz. A large simulation of neutrino interactions upstream of the VD will also be carried out to test the veto capability of the proposed design.
- Provide a multidimensional parametetrization capable of enhancing the selection efficiency of Hidden Particles while keeping the purity at nearly 100%. To this end different hidden particles of different masses and couplings will be multidimensionally compared, using machine learning algorithms, with background processes originated by neutrinos and muons. A second paramaterization will also be provided: HNL, Dark Photon, ALP, sgoldstino and neutralino probabilities as a function of the multidimensional properties of each event.
- Develop a neutrino simulation with the decay vessel filled with air instead of vacuum. The goal is to simulate several interactions of neutrinos with the air to test the rejection capability of machine learning algorithms purely based on the kinematic properties of the events. If a good selection efficiency of HP can still be achieved this would mean that the vacuum would not be really needed. Therefore, this work could contribute to significantelly reduce the cost of the experiment.
- Contribute to the implementation in FairShip of different production and decay modes of sgoldstino particles

Medium-term (3-5 years) prospects

The SHiP experiment is expected to be approved for a 3/4-year TDR phase during 2020. Currentely our group is responsible for the Veto Detector and is competing with the Universities of Geneva and Zurich for the construction of the Timing Detector. Over a 3-year time scale we expect to build and test optimised prototypes, for both detectors, and finish our contributions to Techical Design Report of SHiP. By that time an official decision about the choosen technology of the Timing Detector should be taken: RPC vs Plastic Scintillator technology. Since in the meantime the experiment is expected to be approved, in about 3-4 years from now the group should start building the VD according to the final design. The same is true for the TD in case our proposal turns out to be the selected one (provided that the required financial resources are made available, either by the collaboration, national funds or elsewhere).

During this period the team expects to attract more two or three master students and at least one PhD student. On the analysis side the group intends to start a long-term collaboration with the SHiP neutrino group with the goal of being involved in the tau neutrino analyses. We will also continue to contribute to the optimisation of the rejection of various backgrounds mimicking the expected properties of several hidden particles. Since the group is also contributing to the implementation in FairShip of sgoldstino particles, we expect to integrate an analysis group dedicated to the study of light supersimetric particles. Contributions to the optimisation of some reconstruction algorithms are also foreseen, namely the optimisation of the reconstruction of the photons direction in the SplitCarl detector of SHiP (essential feature to reconstruct the invariant mass of an ALP decaying to two photons).

SWOT analysis

Strengths

- The researchers in the team have repeatedly proven to be competent, inventive, productive and reliable.
- The team includes experts on the very competitive technology of RPC detectors.
- The remaining part of the team has strong competences in Geant4 simulations, reconstruction algorithms, DIS physics, Hidden Sector physics via open-charm/open-beauty and machine learning techniques (a plus for the optimization of the SHiP spectrometer).
- The team has not had any difficulties in recruiting students: currently two undergraduate students and one master student integrate the present project.

Weaknesses

- The project was not funded for the 2020-2021 period.

Opportunities

- We believe that SHiP will be a major player in experimental particle physics, with the potential to make a significant breakthrough in the field. To integrate this project from the beginning is thus an opportunity for LIP.

Threats

- The SHiP experiment is recognized by CERN but not yet approved.
- Available financial resources may not be enough for the construction of the Timing Detector of SHiP (but should not be a problem concerning the Veto Detector).

Theses

1 Master

- Guilherme Soares: *"Optimização da selecção de partículas exóticas na experiência SHiP"*, 2019-04-01 , (ongoing)

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

RESEARCH / DETECTOR DEVELOPMENT FOR PARTICLE AND NUCLEAR PHYSICS

RPC R&D

Resistive Plate Chambers (RPC)

Principal Investigator:
Alberto Blanco (15)

4 ***Researcher(s):***
Miguel Couceiro (10), Paulo Crespo (25), Paulo Fonte (30), Susete Fetal (15)

7 ***Technician(s):***
Américo Pereira (8), João Saraiva (65), Luís Lopes (39), Nuno Carolino (5), Nuno Filipe Silva Dias (14), Orlando Cunha (5), Rui Alves (5)

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

1 ***Master Student(s):***
Joana Teixeira (75)

Total FTE:
4.1

Articles in international journals:
2 Direct contributions
International conferences:
2 Oral presentations
2 Posters
3 Proceedings
International meetings:
1 Oral presentation
Completed theses:
1 Master

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 cera mic 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 positions and times (PS-tRPCs), very low maintenance, environmentally robust RPCs for deployment in remote locations, large area fast-neutron TOF detectors and position sensitive thermal neutron detectors. In addition to the development of technology-expanding devices, we keep an interest in RPC's physical modelling and other fundamental issues, such as gas mixture properties and ageing.

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 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.

In contrast to previous years, 2019 has been a successful year in terms of approved projects. On one hand, the project HiRezBrainPET aimed at the development of a PET scanner dedicated to the human brain with sub-millimeter resolution based on the RPC-PET technology was approved within a PT2020 call, with a budget of 120k€ and a duration of 28 months. On the other hand, the project RPCADVANCE (submitted together with Neutron Detector group) to address challenges on the RPC technology (large area ultra low gas consumption (eventually sealed) RPCs, medium area RPCs offering simultaneous accurate measurement of timing and two-dimensional position, and medium area high rate tRPC) targeting CERN experiments and applications for society was approved in "Fundo CERN" call, with 70k euros and 24 months duration.

Sources of funding

PI	Code	Amount	Dates	Description
Paulo Fonte	AIDA-2020	45.000 €	2015-06-01 / 2019-05-31	Advanced European Infrastructure for Detectors at Accelerators
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 €	2020-01-01 / 2021-12-31	RPCADVANCE : Advancement of the RPC detector technology targeting CERN experiments and applications for society *

Total: 335.000 €

(*) Joint project with the Neutron Detectors Group

RPC R&D

Lines of work and team organization

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

The **RPC-PET** technology already applied successfully in pre-clinical PET, where it reached or exceed the target spatial resolution, has the potential to be applied in human brain PET with the capability to change the paradigm in the diagnosis and investigation of diseases of the central nervous system and to play an important role in the characterization of vascular injuries due to the spatial resolution reachable. 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.

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 are 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.

Autonomous RPCs, able to operate outdoors, reliable, performant, and solar panel powered, are a rather interesting technology for cosmic ray experiments. In particular, sealed RPCs will be a breakthrough in the field, and our group is the world leader. Responsible: L. Lopes.

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

Stated objectives for past year

- Finalize the upgrade of the existing RPC-PET to a pre-commercial small-animal scanner and continue supporting the PET examinations at ICNAS.
- Finalize the data analysis of the data gathered at CERN with the RPC-TOF-FD/SHiP prototype and publish results. After validation, the construction of four modules for the HADES-FD will be done.
- Design, construct and test the first station of STRATOS.
- Finalize the data analysis of the TRISTAN latitudinal survey and publish results. Continue supporting the TRISTAN operation.
- Construct and test the portable cosmic ray telescope for the muon tomography project MUTOM.
- Finalize the MARTA FCT/FAPESP production (this task is mainly done by the Detector Laboratory), integration in Brazil and later installation at the Auger site.
- Perform the low pressure (high altitude) development/measurements for LATTES.
- Continue the development of the sealed RPC chambers.

Achievements and responsibilities during the past year

With the approval of the HiRezBrainPET project the stated objectives in RPC-PET line have had to be changed. The upgrade of the existing RPC-PET installed at ICNAS has been postponed to give priority to the R&D necessary for HiRezBrainPET, although support for its operation has been guaranteed having performed 30 exams during 2019. The HiRezBrainPET project was started in the middle of the year. The conceptual design was developed, covering the main system components and fundamental alternatives. A preliminary study using existing hardware allowed to test together the main system components: trigger and position electronics, readout electrodes, detectors (30x30 cm² x 5gaps), electrical shielding, DAQ noise, etc. The parts of this study directly dependent on the detectors are still ongoing. Pre-existing front-end electronics modules were evaluated for this task and new, higher density, versions were designed, produced, and are now being tested. Likewise, solutions were procured and found for the DAQ system (based on GSI's TRB3 platform) and data storage and processing. Production/acquisition is now under way.

The prototyping work on the TOF detector for the forward region (RPC-TOF-FD) of the HADES spectrometer and the timing detector (TD) for the future SHiP experiment, together with a new detector for the timing tagging of the particles exiting the SHiP Scatter Neutrino Detector (SND), have been carried out as described in the respective group reports.

Prototyping work on the cosmic ray telescopes for STRATOS is severely delayed, but significant progress has been made in developing industrial methods for the production of sealed glass stack (SGS) with new materials with improved sealing characteristics and in the data acquisition system (based on GSI's TRB3 platform).

The operation of the TRISTAN detector was guaranteed during 2019, the year in which it returned from Antarctica, it was operational for several months in Santiago de Compostela together with the TRAGALDABAS detector and returned again to Antarctica (making a second latitudinal survey) where it will remain operational (during the summer months) at Spanish Juan Carlos I base. This has provided an invaluable experience in detector remote operation.

The analysis of the data from the first latitudinal survey, showing a precise and stable (< 1%) measurement of the cosmic ray flux, is being performed and the preliminary results will be presented at the beginning of 2020 at the RPC2020 workshop.

During 2019, the MUTOM telescope (a four plane MARTA like RPC telescope equipped with low power consumption electronics capable of operating with solar panels) has been designed and built in LIP infrastructures. Preliminary tests with all the final sub-systems point to the correct functioning of the system. Only the definitive integration of all its components is missing to be ready for field operation. MUTOM is a joint activity with the AUGER Group (more information in the corresponding group report).

The production of the MARTA FCT/FAPESP detectors was completed in 2019 (for more information on this project, please refer to the AUGER and Laboratory Detectors group reports).

The development of the RPC chambers for high altitude operation, for the LATTES project, is slightly delayed, but all the elements (hypobaric gas box and instrumentation) are now ready.

During 2019 several prototypes of sealed chambers were made and at this moment a "final" design with promising results is being tested.

Lines of work and objectives for next year

- 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.

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 learned 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 together with the R&D needed for the SHiP experiment, although this depends largely on the short-term future of the experiment. On the other hand, STRATOS detector will be finished in the short-term and the continuation of the collaboration with the Hidronav company, with the aim to 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 the “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), which might benefit from the recent opening of a Portugal-CERN PhD grants call.

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 funding of the order of millions, 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 (2019 is an exception).
- 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

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

- *"Multi-purpose trigger system for medium particle detector devices"*, F.Clemêncio, A.Blanco, N.Carolino, C.Loureiro, NIMA 929 2019 142-147
- *"Long term experience in Autonomous Stations and production quality control"*, L. Lopes, A. B. Alves, P. Assis, A. Blanco, N. Carolino, M. A. Cerda, R. Conceição, O. Cunha, C. Dobrigkeit, M. Ferreira, P. Fonte, L. de Almeida, R. Luz, V. B. Martins, L. Mendes, J. C. Nogueira, A. Pereira, M. Pimenta, R. Sarmento, V. de Souza, B. Tomé, J. Instrum. 14 (2019) C07002

3 International Conference Proceedings

- *"ORCA (Antarctic Cosmic Ray Observatory): 2018 Latitudinal Survey"*, ORCA collaboration, PoS(ICRC2019)1059
- *"MIDAS: A particle identification tool for the TRAGALDABAS Cosmic Ray telescope"*, TRAGALDABAS collaboration, PoS(ICRC2019)072
- *"The TRISTAN Antarctic Cosmic Ray detector"*, TRISTAN collaboration, PoS(ICRC2019)071

Presentations

2 Oral presentations in international conferences

- *"ORCA (Antarctic cosmic ray observatory): 2018 Latitudinal Survey, preliminary results "*, 2019-04-07, EGU2019, Vienna, Austria
- *"ORCA (Antarctic Cosmic Ray Observatory): 2018 Latitudinal Survey"*, 2019-07-24, 36th International Cosmic Ray Conference ICRC2019, July 24th - August 1st, 2019 Madison, WI, U.S.A

2 Poster presentations in international conferences

- *"The TRISTAN Antarctic Cosmic Ray detector."*, 2019-07-24, 36th International Cosmic Ray Conference ICRC2019, July 24th - August 1st, 2019 Madison, WI, U.S.A.
- *"MIDAS: A particle identi cation tool for the TRAGALDABAS Cosmic Ray telescope"*, 2019-07-24, 36th International Cosmic Ray Conference ICRC2019, July 24th - August 1st, 2019 Madison, WI, U.S.A.

1 Oral presentations in international meetings

- *"Large area Resistive Plate Chambers at LIP-Coimbra"*, 2019-04-26, Joint Workshop LIP/IGFAE , Santiago de Compostela, Spain

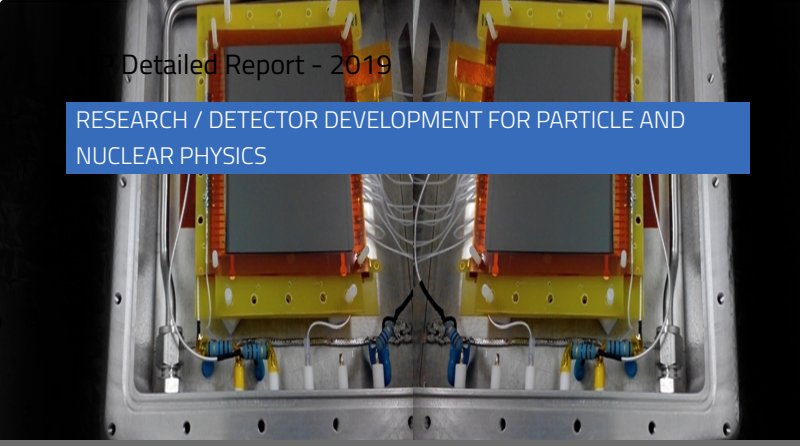
Theses

1 PhD

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

1 Master

- Joana Teixeira: *"Automation of co-registration of pre-clinical RPC-PET images with animal MRI"*, 2018-09-01 / 2019-09-27, (finished)



NEUTRON DETECTORS

Neutron detectors

Principal Investigator:
Luís Margato (75)

3 ***Researcher(s):***
Alberto Blanco (5), Andrey Morozov (31), Paulo Fonte (13)

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

Total FTE:
1.3

Articles in international journals:
3 Direct contributions
International meetings:
2 Oral presentations

Executive summary

The research activities of the group are focussed on the development of innovative thermal neutrons detectors for applications in neutron scattering science, mainly in the framework of large-scale detector R&D programmes in partnership with the world-leading neutron facilities such as ILL (https://www.ill.eu/), ISIS (https://www.isis.stfc.ac.uk/Pages/home.aspx), FRMII (https://www.frm2.tum.de/en/home/) and ESS (https://europeanspallationsource.se/). For more than 15 years that continuous and fruitful collaboration has been pursued through the successive EU-funded projects NMI3-FP6, NMI3-FP7 and, during the last 4 years, SINE2020 - H2020 (https://sine2020.eu/).

Neutron detectors are a critical component of neutron scattering instruments, finding application in a wide range of disciplines including material, chemistry, biology, life and heritage sciences, homeland security and industry. The drastic shortage of ^{3}He during the last decade and the ongoing construction of new high intensity spallation neutron sources, most importantly the European Spallation Source (ESS), strongly motivated the development of alternative neutron detection technologies to replace the one based on ^{3}He. Currently the emphasis is on the development of detectors with high rate capability, high spatial resolution and fast timing, which are able to meet the requirements of a new generation of instruments, such as, e.g., reflectometers and diffractometers to be installed at ESS.

The group has recently introduced and is developing a pioneering concept of a position sensitive thermal neutron detector (PSND) based on RPCs lined with $^{10}B_4C$ solid neutron converters. This technology offers very high spatial and time resolution in comparison with competitive technologies. Also, the practical advantages of detectors of this type are manifold: high modularity of the design, robustness, good scalability and low cost per unit area, as was already demonstrated by application of RPCs in large-area detectors for High Energy and Astroparticle physics.

The group has already demonstrated that this technology is capable to provide high (>60%) detection efficiencies for thermal neutrons and is very well suited for neutron imaging: a prototype of ^{10}B-RPCs PSND with 2D position readout, tested at neutron beam, has shown a spatial resolution of 0.25 mm FWHM, which is unprecedented for large area detectors. The work performed this year has resulted in several important breakthroughs. An experimental study has demonstrated that this type of detector can be operated with gamma sensitivity better than 10^{-6} for 0.511 MeV photons, satisfying an important requirement for detector applications at high background conditions. Several new detector prototypes featuring low resistive materials for RPC electrodes were tested at the HZB neutron source in Berlin. The results show an order of magnitude increase in the maximum counting rate compared to the previous generation of single-layer RPC detector. Combined with an order of magnitude improvement in the rate expected from simulations for a multilayer detector, these results show that the current limit on the counting rate density can be improved by two orders of magnitude, reaching in perspective 100 kHz/cm^2, which is one of the most important milestones on the way to broad implementation of these detectors.

Sources of funding

PI	Code	Amount	Dates	Description
Luís Margato	654000 SINE2020	161.913 €	2015-10-01 / 2019-09-30	World class Science and Innovation with Neutrons in Europe 2020 – SINE2020
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: 231.913 €

(*) Joint project with the RPC R&D Group

Neutron Detectors

Lines of work and team organization

The main focus of the group is on the development of an emerging (and, potentially, disruptive) neutron detection technology which combines Resistive Plate Chambers (RPC) and solid state neutron converters containing boron-10 isotope. The ongoing work is performed along three lines with the main goal to make ^{10}B-RPC technology an attractive candidate for neutron scattering science instruments at large-scale neutron facilities:

- **Increase of the counting rate capability**

This line is essential as the new neutron spallation source facilities put strong rate requirements on the detectors to fully benefit from high neutron fluxes. The research activities include material studies, development of detector designs which implement multi-layer architectures, Monte Carlo optimization studies and work on the readout electronics.

- **Reduction of the gamma sensitivity**

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 activities include both optimization of the RPC design (simulations and prototyping) as well as basic research since there are still many unknowns in the operation of RPCs in the conditions needed to make efficient neutron detectors.

- **Improvement of the imaging capabilities**

While we have already demonstrated a spatial resolution of 0.25 mm, unavailable to most of the competitive technologies, there is a potential to approach 0.1 mm resolution, opening new possibilities for neutron science instrumentation. Work is ongoing on optimization of the readout and introduction of new image reconstruction methods, targeting a significant increase in image linearity and uniformity. Using the capability of RPCs to accurately pinpoint in time the moment of neutron capture, we investigate the capabilities of ^{10}B-RPC detectors to introduce a new modality: time-resolved (and, on a spallation source, energy-resolved) neutron imaging.

The team core 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 on RPC development) and Paulo Fonte (an expert in the physics of RPC detectors). The group has strong connections to the RPC group of LIP and is benefiting from the practical expertise on the RPC detector development accumulated there. Another important resource is assistance from the Detector Laboratory (DL) and Mechanical Workshop (MW) of LIP for manufacturing detector components.

Stated objectives for past year

- MC-simulations with ANTS2 and GEANT4 toolkits: to find the most promising 10B-RPC detector design for high counting rate and strong gamma ray discrimination.
- Materials testing for the RPC's electrodes favoring high counting rate.
- Development of several ^{10}B-RPCs prototypes with different resistive materials for evaluation on a neutron beamline to characterize their performance focusing on counting rate capability.
- Demonstrate that the sensitivity of ^{10}B-RPCs to gamma rays can be less than 10^{-5} for 0.511 MeV.
- Perform simulation (ANTS2) and optimization of a compact PSND with a lithium glass scintillator, coupled to SiPM or PMT arrays to establish the best set of parameters (e.g. scintillator thickness, light guide properties and photosensor arrangement) that optimizes the detector performance.
- Collaboration with a group from FZ Jülich on the development of a compact neutron detector.

Achievements and responsibilities during the past year

All main objectives defined for this year have been achieved and the work has resulted in several important breakthroughs. Two papers were published and two more are in the final stage of preparation. Two oral communications were presented at the SINE2020 General Assembly in Bilbao (Spain). A visiting PhD student from FZ-Julich (Germany) has stayed in our group to receive training in use of ANTS2.

- **Counting rate**
  - Five prototypes of single-gap ^{10}B-RPC detector were constructed using different materials and thickness of the resistive electrode. The maximum counting rate densities for the prototypes were measured at the V17 beam line at HZB in Berlin. Compared to the previous results (rate limit of 1 kHz/cm^2), an increase of 4, 15 and at least 30 times (limited by the available neutron flux) were demonstrated for RPCs with thin soda lime glass, ceramic and silicate glass anodes, respectively.
  - Monte Carlo simulations have shown that a multilayer ^{10}B-RPC detector with 20 gas gaps has maximum counting rate 16 times higher compared to the single-gap RPC. Combined with the result of (1), a 20 gas-gap 10B-RPC with silicate glass anodes should be able to operate at rates higher than the target value of 100 kHz/cm^2.

- **Gamma sensitivity**
  - A sensitivity to gamma rays less than 10^{-6} and 10^{-5} were demonstrated for 0.511 and 1.27 MeV gamma rays, respectively, in an gamma-gamma angular correlation measurements using a ^{22}Na gamma source. It was also demonstrated that the sensitivity can be further reduced by lowering the RPC polarization voltage.
  - A simulation study was performed with Geant4 demonstrating that a modification of the detector design (thinner electrodes and narrower gas gaps) can decrease the gamma sensitivity by an order of magnitude.
- **Imaging capabilities**

Detailed scans of the field-of-view for a double-gap ^{10}B-RPC detector prototype were performed with narrow neutron beams (0.2 mm wide) at the V17 beam line at HZB in Berlin. High-statistics datasets with known exact (0.1 mm precision) positions of the beam are now available for future work on development and optimization of position reconstruction techniques.

- **Development of simulation tools**

A possibility to delegate particle transport simulations to Geant4 was introduced to the ANTS2 toolkit. Using this feature, a cross-validation study was performed demonstrating that Geant4 and ANTS2 simulations give very similar predictions on the energy deposition in RPC gas-gaps following a neutron capture event. This result is very important for future detector optimizations which we plan to perform using ANTS2 semi-supervised detector optimization tools.

- **Scintillator-based detectors**

A neutron Anger camera using a lithium-6 loaded cerium activated silicate glass scintillator coupled to an array of 64 silicon photomultipliers has been assembled. The camera design was optimized using Monte Carlo simulations. A statistical method, implemented on a graphics processing unit (GPU), was used for reconstruction of the scintillation events. Adaptive response reconstruction procedure, similar to the one developed in the Gamma camera group of LIP, was implemented, which gives the detector unique self-calibration capabilities. The results of the camera characterization were reported in a paper published together with the detector group from ILL (France).

Lines of work and objectives for next year

In 2020, we will proceed with the research work focused on boosting the counting rate capability of ^{10}B-RPC based PSNDs, improving the spatial resolution and minimizing as much as possible the gamma sensitivity. This work will be performed in synergy with the RPC R&D group in the frame of the project RPCADVANCE (CERN/FIS-INS/0009/2019) recently funded by FCT (70 kEuro).

The main lines of work and objectives for 2020 are:

- **Increase of the counting rate capability**
  - Study feasibility to use new materials with electrical resistivity between 10^{9}-10^{11} ohm.cm for multilayer ^{10}B-RPC detectors in terms of homogeneity, aging effects, minimum thickness and robustness.
  - Build several small-area RPC prototypes. Characterize the counting rate capability, operation stability, dark current and scalability to large areas.
  - Investigate the effect of electrode thickness and temperature on the counting rate capability.
- **Reduction of the gamma sensitivity**
  - Perform Geant4 simulations to study the effect of the new materials on the RPC gamma sensitivity and neutron scattering inside the detector.
  - Optimize the detector configuration targeting to decrease the energy deposition in the gas gap due to Compton electrons in order to reduce gamma sensitivity
- **Improve imaging capabilities**
  - Investigate performance of several reconstruction methods in order to improve the image linearity and uniformity.
  - Explore new designs for signal pickup electrodes targeting to increase the spatial resolution.

Medium-term (3-5 years) prospects

In the medium-term, one of the major goals is to develop, optimize and assemble a demonstrator of a ^{10}B-RPC PSND and then characterize it on a neutron beamline at a large-scale neutron facility (ILL, ISIS or FRM II) in near real-world conditions, increasing the Technical Readiness Level of ^{10}B-RPC technology and establishing a benchmark for this novel detector type.

On the way towards this goal, in the frame of the RPCADVANCE (CERN/FIS-INS/0009/2019) project, it is planned to design and build a first prototype of a ^{10}B-RPC based neutron detector with improved performance in collaboration with the RPC group. The main objective is to meet detector requirements in terms of efficiency, spatial resolution and counting rate capability for neutron scattering science instruments, such as, e.g., neutron diffractometers and reflectometers.

We also plan to explore a possibility to apply this novel neutron detection technology for the measurements of beta delayed neutron emission probability from very exotic nuclei at ISOLDE at CERN. If the prototype shows that this technology is a valid option, together with the NUC-RIA and RPC R&D groups of LIP we will apply for funding to develop a ^{10}B-RPC detector for these experiments.

The R&D activities on the ^{10}B-RPC based neutron detection technology are of paramount importance for LIP to strengthen synergies with the world-leading neutron facilities (ESS, ILL, ISIS and FRMII) and maintain the capacity to develop innovative detectors for frontline research. Moreover, this work is strategic for future funding opportunities within the next EU framework programme (FP9).

In the medium term, we are considering prospects of developing a fast neutron spectrometer for real-time measurements. This new line of research has a potential to create a strategic goal for LIP in the areas of medical applications (e.g. neutron dose monitoring in hadron therapy) and homeland security (e.g. detector for active-interrogation systems for nuclear security).

SWOT analysis

Strengths

The team has accumulated an extensive knowledge in detector physics and all the stages of detector development, including design, simulation-based optimization, prototyping and characterization at neutron beamlines. The group has well-established ties with international partners (groups from world-leading large scale neutron facilities, such as, e.g. ILL, ISIS, FRMII and ESS), which not only provides access to neutron facilities but also brings new financing opportunities based on EU funds. The group has access to the Detector Lab and Mechanical Workshop at LIP-Coimbra, ensuring the capability for manufacturing of complex components needed to construct detector prototypes.

Weaknesses

The currently available manpower is quite limited: the group's combined FTE is about 1.5. It is not possible to attract PHD students and postdocs due to lack of funding.

Opportunities

ESS, currently under construction in Sweden, will be the world's most powerful pulsed neutron source. The ESS strategic decision not to consider He-3 based detectors (gold standard in neutron scattering science) in the design of its suite of instruments is a challenge which motivates development of new types of detectors with cutting edge performance. This opens an opportunity for the group to participate in this endeavor. In particular, the 10B-RPC neutron detection concept, recently introduced by the group, has a strong potential for future applications as at large scale neutron science facilities as well as in homeland security and industry.

Threats

Limited and not-sustainable funding is the main threat. While a joint proposal submitted with the RPC R&D group to FCT (CERN 2019 call) was selected to be financed, from the requested budget of 240 KEuro only 70 KEuro euros were allocated to the project (RPCADVANCE - CERN/FIS-INS/0009/2019), which is insufficient to fully realise the planned activities.

Neutron Detectors

Publications

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

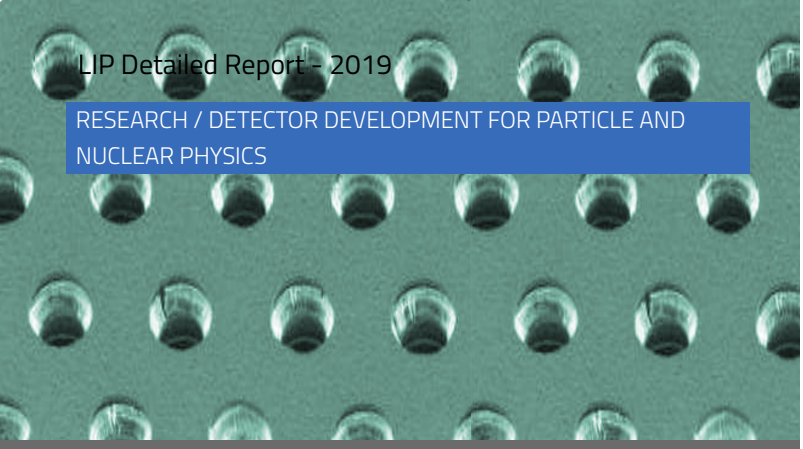
- *"SiPM-based neutron Anger camera with auto-calibration capabilities"*, A. Morozov, J. Marcos, L. Margato, D. Roulier, V. Solovov, arXiv:1902.04513 [physics.ins-det]
- *"Boron-10 lined RPCs for sub-millimeter resolution thermal neutron detectors: Feasibility study in a thermal neutron beam"*, L.M.S. Margato, A. Morozov, A. Blanco, P. Fonte, F.A.F. Fraga, B. Guerard, R. Hall-Wilton, C. Höglunde, A. Mangiarotti, L. Robinson, S. Schmidt and K. Zeitelhack, 2019 JINST 14 P01017
- *"SiPM-based neutron Anger camera with auto-calibration capabilities"*, A. Morozov, J. Marcos, L. Margato, D. Roulier, V. Solovov, 2019 JINST 14 P03016

Presentations

2 Oral presentations in international meetings

Andrey Morozov: *"Update on ANTS2"*, 2019-05-28, SINE2020 General Assembly 2019, Bilbao, Spain

Luís Margato: *"Development of Resistive Plate Chambers (RPCs)"*, 2019-05-28, SINE2020 General Assembly 2019, Bilbao, Spain



GASEOUS DETECTORS R&D

Gaseous Detectors R&D

Principal Investigator:
Filomena Santos (45)

5 ***Researcher(s):***
Carlos Conde (30), Filipa Borges (45), Jorge Maia (15), José Escada (70), João Barata (45)

1 ***PhD Student(s):***
Alexandre Fonseca Trindade (70)

1 ***Master Student(s):***
Afonso Marques (50), David Marques (50)

1 ***External collaborator(s):***
André Cortez

Total FTE:
4.2

Articles in international journals:
3 Direct contribution
5 Indirect contribution

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. Monte Carlo simulation homemade codes are used, together with prototypes of gas detectors developed by the group, and experimental systems adequate for the measurement of relevant quantities. The knowledge acquired by the group in the last years allowed to establish international collaborations, namely with the NEXT collaboration that uses a high pressure electroluminescent Xe TPC to search neutrinoless double beta decay and with the RD51 collaboration, that aims at developing new techniques for gaseous detectors with microstructures.

Sources of funding

PI	Code	Amount	Dates	Description
Vitaly Chepel	CERN/FIS-INS/0025/2017	70.000 €	2018-05-01 / 2020-04-30	Participation in RD51 *

Total: 70.000 €

(*) Joint project with the Liquid Xenon R&D Group

Gaseous Detectors R&D

Lines of work and team organization

There are three main lines of work in our group:

- Ion mobility measurements (positive and negative) in the framework of RD51 collaboration.
- 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).
- Development of novel geometries for high pressure gas detectors, with the aim of producing an industrial prototype, based on the prototype of the HPXe detector developed in the last years and already tested for alpha particles.

Stated objectives for past year

The prototype to measure negative ion mobility is fully assembled but is still being tested. The MSc student is continuing his project and testing the different parts of the system.

Our involvement in NEXT continues, with studies both with experimental and by simulation, namely studies on the electroluminescence for mixtures which may be used in the future in this experiment to reduce the electron diffusion. Xe-He (or other additives) mixtures are one of the mixtures to study. Also, the experimental system to measure the drift parameters in gases should be fully operational and their first results will be analysed, namely their comparison with available data from the literature or our own Monte Carlo simulation results. The validation of the results will allow to confidently evolve to other unexplored gas mixtures, namely to the ones being considered in the NEXT experiment.

Concerning the development of the HPXe detector, an upgrade considering its use for gamma-ray detection is being done. This upgrade will require further studies, and simulation of the detector behaviour (with Geant4 package), since the track of electrons for this radiation will be quite different from that of alpha particles. The simulation will indicate the problems to be addressed first, namely solid angle correction, or different grid biasing and next steps to take to optimize the detector. These studies were initiated by a MSc student, but further manpower will be needed to complete this item successfully.

Achievements and responsibilities during the past year

The on-going studies of positive ions' mobility (within the frame of RD51 Collaboration) has continued and produced some important results, namely with the measurement of the ion mobility in gases to be used in the LCTPC collaboration (Ne-CF4, and Ar-iC4H10). The negative ion system is fully assembled but there are some issues with its performance that still need to be studied and tested.

Concerning the NEXT Collaboration, the experimental system to measure electron drift parameters is fully operational and results are being analysed for known gases to assess the validity of the measurements. Although the system to measure the electroluminescence yield and charge gain of noble gases doped with different additives is available, further studies were not accomplished due to the lack of manpower.

Concerning the development of the HPXe detector, simulations of the absorption of gamma-rays and drift of the resulting primary electrons were performed using GEANT4 code. The results are being still analysed and the simulations will have to be upgraded in order to achieve more confident conclusions. This work was made by a MSc student as part of its final thesis.

Lines of work and objectives for next year

During the next year the negative ion mobility measurement system will be fully operational and experimental results are expected, namely with SF6 and mixtures of this electronegative gas with other gases. First results will be obtained in progressive steps, according to the different operating stages of the device, in order to assess the validity of the results.

The measurement of electroluminescence yield and charge gain of noble gas mixtures doped with these electronegative gases is also a possibility, since the use of electronegative dopants, namely in large volume detectors that require accurate track reconstruction, is a subject that has received recently attention in the scientific community. The experimental systems to do such measurements are available, and this work is only depending on the availability of manpower. Contacts are under way that may establish collaborations with foreign groups. This may allow to obtain more manpower or financing.

Our involvement in the NEXT Collaboration will continue and the questions raised within the collaboration namely with the understanding of unexplained features of the functioning of the presently working prototype (NEW-White) will be addressed by the group. In fact, some unexpected issues of the detector behaviour in

the operation stages, like the appearance of light signals with unexpected intensity, that may be related to the existence of high reduced electric fields near the grid, or secondary production of electrons in the grids or detector walls need to be clarified before moving to the larger prototype, since these issues may compromise the next upgraded version, namely concerning energy resolution and tracking capability. The study of the different possible origins for these effects, by simulation, using Monte Carlo codes adapted from previous ones will be import for the NEXT collaboration. Complementary experimental tests (in adapted devices which will mimic the NEW-White environment) are also under way to try to understand these effects and compare the experimental results with the simulation ones.

Further results for electron drift parameters and drift velocities will be obtained, namely in gaseous mixtures of interest for the NEXT experiment.

Concerning the development of new detectors, the line of work introduced with the HPXe detector prototype will continue, eventually using GEANT4 simulation. From the results obtained from this simulation, some changes in the detector may be made to allow its use for gamma-ray detection. Experimental testing of the detector with the more important changes applied is one of the principal objectives in this line of work.

Medium-term (3-5 years) prospects

The objective of the group for the upcoming years is to develop novel geometries for gas detectors, with the aim of eventually producing an industrial prototype and answer the needs in the challenging range of high and low energy detection. This will follow the line of work that lead to the development of the HPXe detector, and eventually the development of detectors in the very low energy range.

We also intend to use the knowledge acquired to improve gas parameters measurements and simulation studies, allowing for the broadening of the scope of our studies, namely the study of negative ion mobility (needed for the NITPC's), diffusion coefficients and drift velocities of both electrons and ions. This will be made with a special focus on the needs of the NEXT and RD51 collaborations or eventually other collaborations that may be achieved in the next years. Monte Carlo simulation expertise, with custom made and adaptable codes, will also be an invaluable asset either as a first approach or as a cross check to the experimental results.

The study of electroluminescence for gaseous mixtures, namely those that use electronegative dopants is also a field that may be explored and originate further collaborations with groups that are investing in this new approach of gas detectors.

Future work for the next 5 years will also depend on issues that will arise in these international collaborations. In the case of NEXT, it will surely depend on the assembly and first tests with the 100 kg TPC and the issues raised when the prototype starts acquiring data. The available funding and human resources, that has been very uncertain in the last years, is also an issue that will surely constrain the investigation that will be developed by the group.

SWOT analysis

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

Opportunities 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 fullfil the information gaps, and our Monte Carlo simulation skills, with custom made adaptable code, is a first approach to potentially relevant mixtures to study.

Publications

3 Articles in international journals

(with direct contribution from the team)

- *"Experimental ion mobility measurements in pure iC4H10 and Ar-iC4H10 mixtures",* A.F.V. Cortez, M.A.G. Santos, R. Veenhof, J. Escada, P.N.B. Neves, F.P. Santos, C.A.N. Conde and F.I.G.M. Borges
- *"Experimental ion mobility measurements in Ne-CF4",* D.J.G. Marques, A.F.V. Cortez, J. Escada, R. Veenhof, P.N.B. Neves, C.A.N. Conde, F.P. Santos and F.I.G.M. Borges
- *"Experimental ion mobility measurements for the LCTPC collaboration",* A.F.V. Cortez, M.A.G Santos, R. Veenhof, P.N.B. Neves, F.I.G.M. Borges, C.A.N. Conde, Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 936, (2019) 451-452

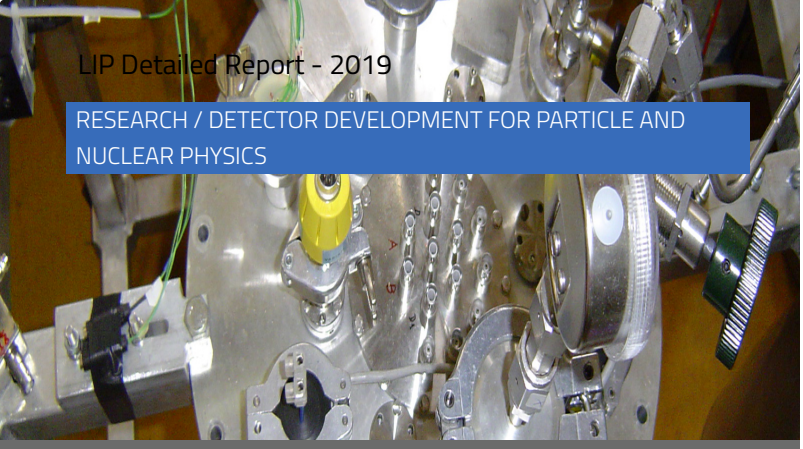
Theses

1 PhD

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

2 Master

- David Marques: *"Negative ion mobility measurement in gases of interest for NITPC's",* (ongoing)
- Afonso Marques: *"Studies with electroluminescent Time Projection Chambers for rare event detection – participation in the NEXT Experiment",* (ongoing)



LIQUID XENON R&D

Liquid Xenon R&D

Principal Investigator:
Vitaly Chepel (40)

3 ***Researcher(s):***
Francisco Neves (20), Luís Margato (25), Vladimir Solovov (20)

Total FTE:
1.1

Executive summary

In the year 2019 the work of the group Liquid Xenon R&D Group has been strongly conditioned by the lack of qualified human resources. A benchtop setup for measurements in vacuum and xenon gas has been assembled and tested. A proposal for further funding in the framework of RD51 Collaboration joining LIP, University of Coimbra and University of Aveiro has been approved with reduced funding. For the next 2-3 years, we will continue to work in the framework of the RD51 project on studying the nature of sattelite signals in liquid xenon double phase electroluminescence TPCs and opertaion of THGEMs in double phase xenon.

Sources of funding

PI	Code	Amount	Dates	Description
Vitaly Chepel	CERN/FIS-INS/0025/2017	70.000 €	2018-05-01 / 2020-04-30	Participation in RD51 *
Vitaly Chepel	CERN/FIS-INS/0026/2019	35.000 €	2020-11-01 / 2022-10-31	Participation in RD51 - Development of Detectors with micro-structures

Total: 105.000 €

(*) Joint project with the Gaseous Detectors R&D Group

Liquid Xenon R&D

Lines of work and team organization

There is a number of experiments around the world using liquid xenon as detector medium. These include search for lepton number violating muon decay, dark matter searches, neutrino physics and double beta decay. Although the energy ranges of interest of 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.

Stated objectives for past year

Start working in the framework of the RD51 project. Develop and manufacture a benchtop setup for studying secondary effects in xenon electroluminescencce TPCs (gas and liquid). Perform tests of different techniques of electronic excitation of xenon and construction materials in the ultraviolet wavelength region.

Achievements and responsibilities during the past year

A benchtop setup for measurements in vacuum and xenon gas has been assembled and tested. A proposal for further funding in the framework of RD51 Collaboration joining LIP, University of Coimbra and University of Aveiro has been submitted to the national CERN Fund 2019 call. Very much reduced funding has been received.

Lines of work and objectives for next year

Continue working on the RD51 project.

Medium-term (3-5 years) prospects

For the next 2-3 years, to work in the framework of the RD51 project on studying the nature of sattelite signals in liquid xenon double phase electroluminescence TPCs and opertaion of THGEMs in double

SWOT analysis

Strenghts

Highly qualified members of the laboratory with many years of experience in the field and willingness to contribute to R&D in liquid xenon.

Weaknesses

Unavailability of the quli ed manpower, including the team members, due to their heavy involvement in other activities and projects. Degradation of the experimental basis.

Opportunities

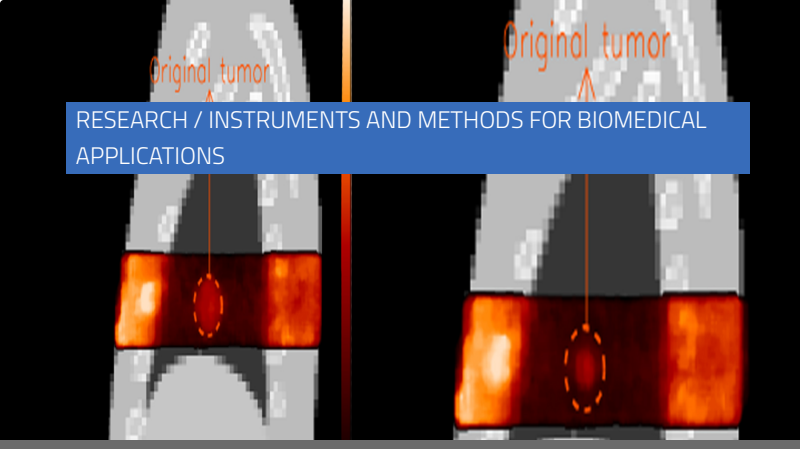
Overcoming the weakness, there is an opportunity of understanding some fundamental aspects of the detector physics and provide a valuable input for future large scale detector development in the framework of the funded projects "Participation in the RD51 Collaboration at CERN".

Threats

Unavailability of the qualified manpower.

[Instruments and methods for biomedical applications]

OR Imaging
Gamma Cameras
Dosimetry



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)

Total FTE:
2.0

International conferences:
1 Poster

Executive summary

The OR Imaging technique may be divided into two main branches: OrthoCT (orthogonal computed tomography) for monitoring megavoltage-based radiotherapy (high-energy X-rays); and O-PGI (orthogonal prompt-gamma imaging) for monitoring particle radiotherapy, viz. proton therapy.

For the past year the experimental work has been put on standby, waiting for the results of both the OrthoCT as well as the O-PGI simulations. In the first case we have managed in the past year to compare Geant4-based Monte Carlo simulations of an OrthoCT system with competing configurations, and a quantitative analysis is ongoing, to which submission to a journal will follow.

Regarding O-PGI, a full system simulation has started. In contrast to the previous simulation studies, in which ideal gamma detectors were considered, this time the goal was to add realistic scintillators to the model and analyze the performance of the O-PGI system. It was demonstrated (and reported at the 2019 IEEE NSS/MIC in Manchester, UK) that for the conditions of proton therapy of the head region O-PGI can be used to determine the position of the Bragg peak with the required 2 mm precision. In a second stage it was established that extension of the model to include optical photons has a significant effect on the performance of the O-PGI and an event discrimination based on the time delay has to be introduced, as well as performance optimization procedures.

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 the PI of this group and to be developed in collaboration with the LIP Dosimetry group in the next two year, approved by the CERN fund.
- "TOF-PET for Proton Therapy (TPPT), in the framework of the Portugal-Austin colllaborative projects, led by PETsys electronics and involving several other institutions in Portugal and in Texas, EUA. LIP is represented by the PI of the OR imaging group.

Sources of funding

PI	Code	Amount	Dates	Description
Paulo Crespo	CERN/FIS-INS/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 (Portugal-Austin colllaborative projects)

Total: 290.442 €

OR Imaging

Lines of work and team organization

The lines of work of the team involve both OrthoCT (orthogonal computed tomography) for monitoring megavoltage-based radiotherapy (high-energy X-rays); and O-PGI (orthogonal prompt-gamma imaging) for monitoring particle radiotherapy, viz. proton therapy. The lines of work are divided in simulation and experimental work. The partnership with two hospitals and the collaboration of LIP's infrastrutures, namely the Detector Lab and the Mechanical Workshop, are crucial for the team.

Stated objectives for past year

Two lines of work were foreseen: (1) the 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; and (2) the 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 so that crystal choice and positioning will certainly be different).

The construction of a small-scale O-PGI system has been already started. The goal is utilizing 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 (PBT) in an experimental facility (e.g. TU Delft in The Netherlands).

Achievements and responsibilities during the past year

For the past year the experimental work has been put on standby, waiting for the results of both the OrthoCT as well as the O-PGI simulations.

In the first case we have managed in the past year to compare Geant4-based Monte Carlo simulations of an OrthoCT system with two competing configurations: (1) a pixelated solution, with finger-like crystals (more expensive solution, potentially yielding images of higher spatial resolution), and a solution comprised by a single, monolithic scintillator (cheaper solution at a potential decrease in system spatial resolution). Visual inspection of all images obtained reveals that the quality obtained with the second system (monolithic scintillator) seems to be of the same quality as those obtained with the former (finger-like crystals). A quantitative analysis is ongoing, to which submission to a journal will follow.

Regarding O-PGI, a full system simulation has started. In contrast to the previous simulation studies, in which ideal gamma detectors were considered, this time the goal was to add realistic scintillators to the model and analyze the performance of the O-PGI system in two stages: first based on the information on the energy deposition in the scintillators and, in the second stage, using signals of the photosensors obtained in simulations considering emission, transport and detection of optical photons. An update and validation of the toolchain was performed, and comprehensive models of the O-PGI system were developed for the Geant4 and ANTS2 toolkits. Several materials, sizes and segmentation types of the scintillator were considered and a geometry with 2 mm x 30 mm x 30 mm GSO scintillators was selected as the most optimal one. In the first stage, based on the deposition analysis, it was demonstrated (and reported at the 2019 IEEE NSS/MIC in Manchester, UK) that for the conditions of proton therapy of the head region (130 MeV protons, 10 ns bunch-to-bunch time, 2 ns FWHM beam width), O-PGI can be used to determine the position of the Bragg peak with the required 2 mm accuracy. In the second stage it was established that extension of the model to include optical photons has a significant effect on the performance of the O-PGI: the required accuracy in the Bragg peak determination cannot be reached without introduction of scintillation event discrimination based on the time delay between energy deposition and the proton bunch time. A technique based on photosensor waveform analysis was developed to compute this time delay, and it was shown that a 2 ns filter range is adequate for proton therapy of the region of the head. It was also established that optical trapping of visible photons in the scintillators due to encapsulation has a strong effect on the O-PGI performance and has to be optimized, although the results already point to a Bragg peak accuracy smaller than 2,6 mm FWHM.

In conclusion, although work is still in progress, in this past year we were able to fully simulate, crystals included, an OrthoCT and an O-PGI system, as foreseen. The results are still being processed and it seems improvements are mandatory, as e.g. the study of YAP as a scintillator crystal instead of GSO in the O-PGI case only (OrthoCT does not profit from the time-of-flight technique to reduce its background events).

Lines of work and objectives for next year

An experimental prototype OrthoCT system has been built with four slices of GSO crystals interlaced by lead sleaves of ca 20 mm x 20 mm x 3 mm each. The readout of the scintillation light was proven feasible with megavoltage X-rays (PhD thesis Hugo Simões). We aim at acquiring a fast oscilloscope in order to prove that the neutron background present in proton beam therapy does not disturb imaging in a proton beam facility (TU Delft, The Netherlands, with oscilloscope-based data acquisition of this same orthogonal ray prototype).

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, at a later stage, real treatments plans may also be simulated, with and without pertinent patient modifications.

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.

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 the PI of this group and to be developed in collaboration with the LIP Dosimetry group in the next two year, approved by the CERN fund.
- "TOF-PET for Proton Therapy (TPPT), lin the framework of the Portugal-Austin colllaborative projects, led by PETsys electronics and involving several other institutions in Portugal and in Texas, EUA. LIP is represented by the PI of the OR imaging group.

Medium-term (3-5 years) prospects

In the framework of 3-5 years 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 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.

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 the PI of this group and to be developed in collaboration with the LIP Dosimetry group in the next two year, approved by the CERN fund.
- "TOF-PET for Proton Therapy (TPPT), lin the framework of the Portugal-Austin colllaborative projects, led by PETsys electronics and involving several other institutions in Portugal and in Texas, EUA. LIP is represented by the PI of the OR imaging group.

SWOT analysis

Strengths

The rotation-free, low-dose imaging capability of both OrthoCT and O-PGI 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 both OrthoCT and O-PGI, together with its real-time imaging making use of the therapeutic beam (conseqeuntly without extra dose to the patient), 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. For O-PGI the robotic system may be less complex due to the smaller volume and weight of the system under investigation.

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 and O-PGI represent an added value in both scenarios: on-board and/or real-time patient imaging.

The installation in Portugal of a centre for proton therapy, with treatment and research facilities, is a clear opprtunity. 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.

Threats

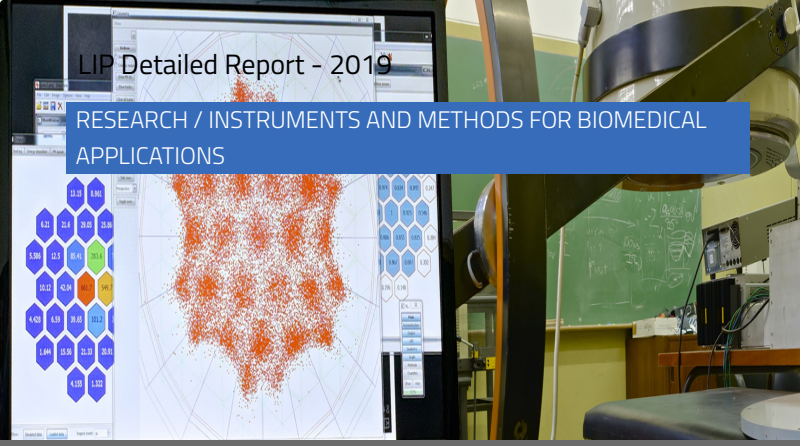
The investment of clinical sites in other IGRT (image-guided radiation therapy) techniques makes investment in the OrthoCT and/or O-PGI techniques questionable for such sites, at least before the return on previous investment(s) is achieved.

OR Imaging

Presentations

1 Poster presentations in international conferences

- Hugo Simões: *"Orthogonal prompt-gamma imaging for in-vivo monitoring of proton therapy treatments: ongoing full detection system simulation"*, 2019-10-26, 2019 IEEE Nucl. Sci. Symp. & Med. Imag. Conf (NSS/MIC), Manchester, United Kingdom



GAMMA CAMERAS

Adaptive methods for medical imaging with gamma cameras

Principal Investigator:
Vladimir Solovov (25)

4 ***Researcher(s):***
Andrey Morozov (30), Francisco Neves (5), Isabel Lopes (20), Vitaly Chepel (30)

2 ***Technician(s):***
Américo Pereira (5), Nuno Carolino (5)

1 ***PhD Student(s):***
João Marcos (100)

1 ***External collaborator(s):***
Luís Pereira

Total FTE:
2.2

Executive summary

The group was formed in 2013 to apply the know-how accumulated at LIP during the previous work on position-sensitive scintillation detectors (PSSD) in the areas of medical imaging and imaging techniques used in drug discovery. In recent years, we have confirmed, both by Monte Carlo simulation and experimentally, the applicability of our auto-calibration and position reconstruction techniques to clinical gamma cameras of classic design and high resolution compact cameras with silicon photomultiplier (SiPM) readout. We created an integrated software tool ANTS2 that incorporates the entire PSSD development workflow: interactive design and simulation via a computer model, as well as experimental data processing, event reconstruction and visualisation. Currently, ANTS2 is actively used by several groups, both inside and outside the LIP. We collaborate with medical imaging units at the University of Coimbra (ICNAS and AIBILI) and at the Hospital Center at the University of Coimbra (CHUC). We continue collaboration with the Radiation Detectors and Applications Group at Politecnico di Milano.

Gamma Cameras

Lines of work and team organization

Autocalibration and fast calibration algorithms for PSSD. In this line of research, we seek to expand the range of detector configurations to which self-calibration techniques can be applied. We are also exploring applications in areas other than medical imaging, such as detectors for astroparticle physics, neutron detectors and RPCs.

Development of simulation, data processing and reconstruction software for PSSD. The open source software package ANTS2, developed by the group, provides a set of easy-to-use tools for simulation and reconstruction of scintillation events in a PSSD of configurable geometry. To our knowledge, it's the only publicly available software package that performs both event and detector response reconstruction for detectors of arbitrary geometry.

Compact clinical cameras with self-calibrating capability. In collaboration with the Department of Nuclear Medicine at the Hospital Center of the University of Coimbra, we are working on the development of a compact portable gamma camera to be used in sentinel lymph node (SLN) surgery with the option to be also used for high-resolution thyroid imaging.

Stated objectives for past year

The following objectives were stated for this group for the past year:

- Integrate Geant4 as a particle simulation backend into ANTS2 package
- Build a prototype of the hand-held camera for sentinel node surgery and thyroid imaging.
- Develop a reliable 3D calibration technique for thick monolithic scintillation crystals.

Achievements and responsibilities during the past year

Development of the ANTS2 software and integration of Geant4 as a particle simulation backend

We developed a particle simulation backend based on Geant4 that accepts the detector geometry defined in ANTS2 in the form of a GDML file, performs all particle simulations using the Geant4 engine and returns to ANTS2 the list of energy depositions and/or particle tracking history. Thus, the detector definition, optical simulation, position reconstruction and data analysis are performed by ANTS2, while particle simulation is delegated to a much more advanced Geant4 tracker. ANTS2 can be also used as a Geant4 front end, used to construct the detector's geometry and explore and analyze the particle tracking history. This capability was extensively used by A. Morozov in his work on a scintillation detector for proton therapy monitoring. To facilitate the deployment of the software, we created a Docker image with integrated ANTS2 and Geant4 backend, which can be downloaded from the Docker Hub.

An update of the ANTS2 GUI has been introduced to facilitate the process of configuring the detector geometry, implementing several features normally offered by CAD software. In addition, a new functionality was introduced in the analysis of the simulation results. A deeply customizable event viewer with graphical representation of the tracks is now available. A powerful system for general-purpose analysis with flexible filtering was implemented. The new analysis features are very useful during the prototyping phase of the detector's development cycle and also significantly increase the attractiveness of Ants2 for didactic applications.

The toolkit is widely used in LIP (by members of the Gamma Cameras group, Neutron Detectors group, Dark Matter, Proton Therapy and Gaseous Detectors, among others). In 2019, there was an increase in the use of ANTS2 in the LZ collaboration, both at LIP and at other institutions. A master class on using ANTS2 for analysis of the calibration data was included in the program of the recent LZ analysis meeting. We also presented (in the framework of activities of the LIP Big Data and Simulation Competence Center) a seminar in Lisbon dedicated to the recent developments of ANTS2.

Portable clinical gamma camera

Based on the discussions with our colleagues from the Nuclear Medicine Department of Coimbra University Hospital (CHUC), we envisioned a simple and cost-effective system: a hand-held gamma imager for assisting sentinel lymph node biopsy surgery that could also be used for thyroid imaging when not employed for surgery. This idea was taken up with considerable interest by the hospital specialists, therefore, we developed a joint project in collaboration with the Nuclear Medicine Department and submitted it to the last PTDC call in May 2017. Unfortunately, the project was not funded. However, João Marcos continued to work towards construction and characterization of the camera prototype as part of his PhD program. The prototype was thoroughly characterized in the series of measurements performed at CHUC. In particular, intrinsic spatial resolution as low as 0.7 mm FWHM has been reported for LYSO crystal and Tc-99m source. Being equipped with specially manufactured tungsten parallel-hole and pinhole compact collimators, the camera demonstrated sufficient resolution for the intended applications. In addition, the portable data acquisition and processing system with integrated front-end electronics demonstrated the ability to reconstruct images in real time from the acquired data.

3D position sensitivity in thick monolithic scintillation crystals

The problem of identifying the depth of interaction in a scintillation crystal existed for quite some time in PET imaging. The current solutions are expensive and/or time-consuming, for example, multiple high-resolution scans with pencil-beam source. There is also interest in measuring interaction position of high-energy gamma rays in large LaBr3:Ce scintillators for high-resolution gamma-spectroscopy of radioisotopes at relativistic velocities and for Compton camera for radiotherapy monitoring.

We have updated previously proposed calibration technique based on scanning by knife-edge gamma-ray beam in orthogonal directions in order to employ a pencil-beam collimated source. Tests on Monte Carlo generated data confirmed feasibility of the proposed method. Unfortunately, the experimental test for this technique, planned for mid-2019, was postponed due to circumstances beyond our control.

Lines of work and objectives for next year

The objectives for the next year are:

- Development and distribution of ANTS2 package.
- Build a prototype of hand-held camera for sentinel node surgery and thyroid imaging.

The work will be organized along the following lines:

Development and distribution of ANTS2 package.

We plan to continue work on the integrated ANTS2 + Geant4 environment for the development of scintillation detectors. The next step will be the creation of an interactive web interface, bringing several advantages: system independence, remote capability, less steep learning curve for beginners. In addition, the web interface can be used to create intuitive tools for demonstrating the working principles of particle detectors in a classroom environment and in outreach projects. In the case of success, it will be developed into a didactic and outreach package described in the medium-term plan.

The increase in the use of ANTS2 by third parties in the last year has allowed us to better understand the possible difficulties that it can present to a novice user. Based on the feedback, we will develop a set of tutorials that would demonstrate how to perform basic tasks, such as simple detector construction, simulation, event reconstruction and data analysis.

During the next year, we plan to update the ANTS2 LRF module, which is used to parameterize and store the detector spatial response. The custom spline library behind the module will be made standalone, allowing it to be integrated with other projects in which LIP (or the simulation competence center) is participating.

One of the most attractive features of ANTS2 is its fast and versatile optical simulation module. We plan to implement several steps (for example, an upgrade of the 3D navigator) to further increase the photon tracing speed. We will also start an ambitious campaign to introduce in ANTS2 the possibility of tracking optical photons on the GPU.

Hand-held camera for sentinel node surgery

A portable gamma camera provides additional information to physicians that may result in improved outcome of SLN surgery. However, for many hospitals the available commercial models are too expensive for a tool that is not used on a daily basis. We proposed to build a prototype of a two-purpose portable gamma camera with sufficient resolution for use in thyroid imaging when not employed in surgery. Our unique know-how in calibration and simulation techniques would allow us to minimize maintenance costs.

This is an attractive direction, as it would allow the development of a practical device for clinical use in close cooperation with physicians, physicists and technicians from the nuclear imaging department of CHUC. The measurement campaign carried out in 2019 on smaller (approximately half-size) prototypes showed very promising results, indicating that the full-size camera would meet the requirements for both SLN and thyroid imaging. Considering that all the main components (scintillator crystal, SiPM array, collimators and data acquisition system) have already been acquired, we are considering the possibility (subject to manpower availability and funding) to build the full-scale camera and test it in collaboration with CHUC. The future strategy in this line will depend on the FCT/European funding policy.

Medium-term (3-5 years) prospects

Web interface of ANTS2: didactics and outreach

Problem: Lack of intuitive tools for demonstrating the working principles of particle detectors in a classroom environment and outreach projects.

What is proposed: Create an interactive system with JavaScript front-end running in a web browser and ANTS2 server as the back-end. Students will be able to study the principles of operation of a detector "in action" by running a set of simulations with the possibility of adjusting key parameters through a web interface with simulation results displayed immediately on the same web page. The standard front-end will feature a simplified configuration interface, integrated with the 3D viewport. It will also be possible (through the ANTS2 script) to configure the front end as different environments: presentation, interactive demonstration, problem solving, questionnaire etc. The web interface can be executed on any device compatible with a modern web browser, including tablets and smartphones, allowing the use of the environments mentioned above in outreach activities, such as presentations at exhibitions and hands-on sessions at schools.

Fast tracing of optical photons

Problem: Monte Carlo simulations of optical photon transport are computationally very expensive. To our knowledge, there is no efficient general-purpose GPU implementation of it up to date.

What is proposed: Take advantage of vector processing (SIMD – Single Instruction Multiple Data) capabilities of modern CPUs to improve photon tracing speed in ANTS2. Based on the work of GeantV and VecGeom teams, an improvement by a factor of 4 can be expected. More radical approach would be to implement photon tracing on Graphics Processing Units (GPU). Some insight can be gathered here from the work done by Opticks and Chroma projects. The expected speed improvement is in the range between x10 and x100 on a modern GPU board.

SWOT analysis

Strengths

- The core members of the team have a proven track record of developing high-performance position sensitive scintillation detectors for several applications including medical imaging.
- The key technology of auto-calibrating scintillation camera was originally proposed and is currently developed by the team members. The team maintains close ties with the Dark Matter group at LIP, lead developer of position reconstruction and auto-calibration algorithms for LUX and LZ experiments.
- One of our key assets is the ANTS2 software package, the only tool that permits to do both statistical event reconstruction and reconstruction of the detector response for a detector of practically arbitrary geometry.

Weaknesses

- Limited experience in dealing with business and industry. We are currently trying to close this gap by more actively seeking partners at the local “enterprise accelerator”.

Opportunities

- Proximity of a large university hospital (CHUC). Doctors are interested in trying out compact gamma camera as a guiding aid during chirurgical interventions.
- The methods and tools developed in the group are of interest for a large community which leads to high potential to form new collaborations.
- We expect that our advance to SPECT/PET reconstruction will attract new students to the team.

Threats

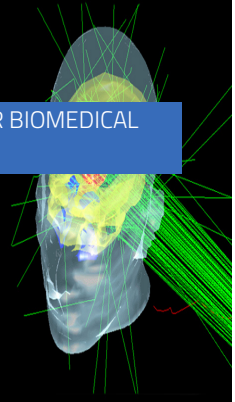
- One of the core team members and lead software developer is on a limited-duration contract.
- The idea of self-calibration threatens large manufacturers’ revenue stream from periodic calibration services - we can hardly expect collaboration from this side.

Gamma Cameras

Theses

1 PhD

- João Marcos: *"Real-time statistical event reconstruction for medical scintillation cameras"*, 2015-01-01 (ongoing)



DOSIMETRY

Dosimetry

Principal Investigator:
Luis Peralta (50)

2 ***Researcher(s):***
Jorge Sampaio (30), Patrícia Gonçalves (10)

2 ***PhD Student(s):***
Dalila Mateus (41), Pamela Teubig (20)

4 ***Master Student(s):***
Ana Campos (20), Duarte Guerreiro (100), Filipa Carvalho (100), José Miguel Venâncio (100)

1 ***Trainee(s):***
Catarina Pimenta

1 ***External collaborator(s):***
Joana Antunes

Total FTE:
4.7

International conferences:
1 Oral presentation
1 Poster
2 Proceedings
Completed theses:
3 Masters

Executive summary

The dosimetry group has a long experience in the design and construction of detectors for medical applications. In the last year, we started to apply this knowledge in the development of new instruments and methods in high-resolution dosimetry. The ultimate goal is to measure doses in submillimetric scales in order to relate more precisely the physical effects of radiation to the biological response of tissues.

For this, we started to test the response of scintillating fibers to proton beams. These tests the preliminary studies for the 3d-DoSkin project that intends to develop a prototype for radio-biology studies based on very thin scintillating fibers. These will have the unique capacity to support the growth of the biological system to be irradiated. In parallel, we have been developing studies based on Monte Carlo simulations in the area of radio-sensitization with nanoparticles. We intend in the future to develop the same type of simulations applied to FLASH therapy with charged particle beams. We have also developed work on improving fundamental atomic parameters related to Auger emitters.

Dosimetry

Lines of work and team organization

The group is divided into two thematic lines:

1. Clinical dosimetry

2. High-resolution dosimetry and microdosimetry

The first line focuses on the application of plastic scintillators and optical fibers in the context of clinical dosimetry for particle therapy. The responsible for this line is Luis Peralta.

The second line focuses on studies of radiation effects at cellular level aiming at determining the biological efficiency and induced damage of high-LET radiation. Jorge Sampaio is responsible for this line of research.

Stated objectives for past year

Carry out the response measurements of a number of different diameter fibers in the existing 2 MeV proton micro-beam at the CTN facility. For low-energy protons the interaction with matter is mostly due to electromagnetic interactions, since most nuclear channels are close. This allows the measurement of direct response to protons, without the contamination from secondary particles, other than electrons.

Achievements and responsibilities during the past year

1. The range uncertainty in proton therapy (PT) adds an additional degree of freedom to treatment planning. Uncertainties in the exact position of the distal dose arise from organ motion, setup and anatomical variations, dose measurements, and biological effects. Reducing these uncertainties allows a better use of the advantages of protons, minimizing their risks. For measurements of proton depth-dose distributions, the gold standard is the use of plane-parallel ionization chambers (PPIC). A fundamental requirement for PT dosimetry is that these detectors have a very good spatial resolution. With PPIC this is of the order of few mm. In this work, we made a study of scintillating fibers' response to protons. Plastic scintillating fibers from Kuraray were tested for scintillation response including the Bragg peak energy range. A setup has been designed to allow the scanning of the proton energy impinging on a single fiber through proton energy loss in air. First tests were performed with 2 MeV protons at the CTN/IST (Lisbon) facilities. Fibers with 1 and 2 mm diameter coupled to a PMT read by an electrometer were tested. The measured energy deposited on the fibers was compared with simulations using the code FLUKA and the code pMC developed within the group. The tests made unveiled some shortcomings of the beam line on CTN, namely a poor alignment system. Overall the performed tests allowed for the development of experimental setup to test single fibers on a proton beam.

2. We also started to investigate the development of a plastic scintillating detector based on an array of very thin juxtaposed fibers. These preliminary works were done in the framework of a Master Thesis and included the simulation of the array response to protons with the code FLUKA. The results show that the system can reproduce well the transversal distribution of the deposited energy with sub-mm resolutions when using the 0.250 mm fibers. However, it is expected that cross-talk effects can affect the multi-channel readout. The work also addressed different coating techniques that could be used to minimize this effect, namely magnetron sputtering, and thermal evaporation. Fibers were also characterized based on Raman spectroscopy and spectrophotometry. A tray to study cross-talk effects that can be coupled to the dedicated test bench (Fibrometer) at LOMAC was designed and produced at LIP´s mechanical workshop.

3. New atomic relaxation data for the Auger emitters I-125 and In-111 was produced using two state-of-art atomic structure codes. Simulations with the code PENELOPE have shown that differences between the new data and the standard EADL data are mostly on the nm range. This is expected, since the biggest differences between the new and the old data are in the very low-energy outer shells transitions.

Lines of work and objectives for next year

1. Radiosensitization efficacy of nanoparticles in proton therapy
Radiotherapy with heavy charged ions allows the energy to be deposited much more localized in the tumor region, minimizing healthy tissue. On the other hand, targeted radiotherapy is a promising modality in the treatment of cancer cells at the molecular level. The addition of nanoparticles (NPs) to the tumor cells has been proposed as a strategy to combine these two new modalities, allowing to reduce the total dose to the patient. The effectiveness of NPs to improve the performance of ion therapy was shown in several radiobiology experiments. However, current Monte Carlo simulations do not explain this enhancement. This enhancement is strongly dependent on the physical, chemical, and biological processes resulting from the interaction of the protons and the NPs. To start understanding these processes, we are implementing Geant4-DNA simulations of photon and proton irradiation experiments of cells doped with gold NPs using the framework TOPAS. The goal is to understand the differences of the track-structure of the energy deposition and the space-time distribution of the chemical species in a cell model depends on several physical parameters density and distribution of the NP inside the cell, and size of the NPs) for the two modalities.
Simulations have shown a larger effect of Au and Pt as dose enhancers, and, more importantly, that this enhancement is mostly due to the cascade of Auger electrons since they have a very high LET. Currently, the data available for microdosimetric calculations are based on the EADL database, where the accuracy of the very low energy transitions (that lead to the high LET Auger electrons) is disputable. For example, Geant4 relies on the “form factor” ECPSSR model to describe the inner-shell ionization process by heavy ions and on the EADL database to describe the atomic deexcitation transition probabilities. Several effects such as electron correlation, satellite transitions, and condensed phase effects are not included in the determination of the Auger spectra. During the next year, we plan to start addressing these issues, namely, producing a new set of atomic parameters for radiosensitive NP (e.g. Au and Pt) using a state-of-the-art MultiCon guration Dirac-Fock (MCDF) code and develop a cascade model code to compute Auger spectra that includes part of the above-mentioned features.

2. 3d-DoSkin
This work intends to demonstrate the feasibility of a new detector for proton radiobiology studies, capable of measuring with sub-millimeter resolution and simultaneously supporting the growth of the biological system to be irradiated. We will develop a real-time dosimetry array consisting of tissue-equivalent material in conjunction with a novel 3-D human skin model. If we succeed in growing cells on the detector, this will open unprecedented radiobiological experiments of the cellular response of the skin to PT and other tissues. The skin is a highly relevant system to demonstrate our concept, as the skin is one of the dose-limiting organs in PT when considering the types of beam delivery (passive scattering or active scanning, uniform scanning or spot scanning).

The detector will be constructed of juxtaposed thin plastic scintillating fibers (PSF) coupled with a readout by a multi-anode photomultiplier assisted by a well-established data acquisition system. The bers' PMMA cladding will be functionalized to allow cell adhesion and tissue growth. Human keratinocytes will be grown on functionalized fibers or scaffolds either as a monolayer, as an epidermis or both dermis and epidermis (together with broblasts) for a full 3D human skin. X-ray and proton irradiation tests will be carried out to con rm the detector's multi-channel response and the biological response of 3D-skin to irradiation. The system will be calibrated to proton beams of different energies at the UT-MDACC.

This proof-of-concept (PoC) project would put us in a privileged position to produce a new class sensor for medical physics applications that are more cost-effective than the solid-state micro-dosimeters under development. If this PoC is successful, at the end of the project we will be able to competitively raise funds for the further development of a complete and qualified system. No commercial micro-dosimeters are currently available in the market worldwide and we strongly believe that our project will provide an in ernationally competitive prototype with great potential for the transfer of technology to the industry.

Medium-term (3-5 years) prospects

In the next 3 to 5 years we intend to develop the 3d-DosSkin project. This project will be developed together with the LOMaC in strong collaboration with biology groups from BioISI/FCUL and ITQB-NOVA. A proposal for financing this project was recently submitted in the UT Austin-Portugal program for exploratory projects, involving the M.D. Andersen Cancer Center. In the coming years, we intend to also involve the radio-biology groups of C2TN/IST and ICNAS to carry out studies with proton beams in Portugal.

We also continue to develop our competences in the application of Monte Carlo simulations, namely, Geant4-DNA to study the physicochemical effects at the cellular level. In this line, another exploratory project with the UT Austin-Portugal program was proposed in collaboration with the M.D. Andersen Cancer Center. LIP will be responsible for the implementation of simulations concerning radio-biology studies with proton beams at very high dose rates (FLASH therapy). At a more theoretical level, we will continue to study the quality of the physical parameters implemented in these simulations and their impact on the dose distributions at nanometer scales.

Students will be involved in these projects at the level of master and doctoral theses.

SWOT analysis

Strengths

Long term expertise in the development of instruments for photon and electron dosimetry. Access to Biophysics and Physics Eng. students since a few members are teaching at University Physics Departments. Collaborations with several healthcare services and health research institutions in Portugal (HSM, IPO, ICNAS, and C2TN). Contacts with researchers and medical physics in forefront hadrontherapy and research centers in Europe.

Weaknesses

The number of FTE researchers is small for the development of the proposed projects. Furthermore, some Ph.D. researchers are in precarious contracts. Difficulty to maintain or attract new students currently finishing the master's degree due to the lack of funding for Ph.D. grants.

Opportunities

The installation of the proton therapy unit in Portugal will give great relevance to the projects proposed in this plan. Specific funds for research and training in this area are expected if the proton therapy unit is commissioned. Two exploratory projects have been submitted for funding to the Portugal-Austin programs and the submission of at least one project to FCT's call in all domains is being prepared. Possibility of developing long-standing international collaborations is also foreseen (USC, HIT, NPL, GSI). Participation in European networks related to proton therapy and dosimetry (EPTN and EURADOS) may open the access to European funding.

Threats

The contractual volatility of several researchers makes the development of this strategic plan over the next five years uncertain. Delay or suspension in the research funding committed to the installation of the proton therapy unit in Portugal may jeopardize the existence of national support to develop this plan.

Dosimetry

Publications

2 International Conference Proceedings

- *"Study of scintillating fibers response to low energy protons"*, D. Guerreiro, L. Peralta, D. Galaviz, J. G. Saraiva, J. M. Sampaio, P. Teubig, 3rd International Conference on Dosimetry and its Applications (ICDA-3)
- *"pMC a fast-low energy proton simulation program"*, Duarte Gurreiro e Luis Peralta, 3rd International Conference on Dosimetry and its Applications (ICDA-3), Lisboa 27-31 maio 2019

Presentations

1 Oral presentations in international conferences

- Luis Peralta: *"Study of scintillating fibers response to low energy protons"*, 2019-05-29, 3rd International Conference on Dosimetry and its Applications (ICDA-3), Lisboa

1 Poster presentations in international conferences

- Luis Peralta: *"pMC a fast-low energy proton simulation program"*, 2019-05-27, 3rd International Conference on Dosimetry and its Applications (ICDA-3) , Lisboa

Theses

1 PhD

- Dalila Mateus: *"Estudos dosimétricos para SBRT/SRT de pequenas lesões do Cérebro"*, (ongoing)

5 Master

- Duarte Guerreiro: *"Estudo da resposta dosimétrica de cintiladores plásticos em feixes de protões"*, 2018-10-01 / 2019-10-18, (finished)
- Filipa Carvalho: *"Conception of a Tissue Equivalent Plastic Dosimeter Using Scintillating Fibres for Hadronic Therapy and Space Radiation Effects Studies"*, 2019-11-07, (finished)
- José Miguel Venâncio: *"Scintillation detectores for dosimetric monitoring in interventional cardiology"*, 2018-03-01 / 2019-12-13, (finished)
- Ana Campos: *"Estudo da dispersão de partículas alfa em filmes finos"*, 2018-07-01 , (ongoing)
- Joana Antunes: *"Simulations of radiosensitization efficacy of nanoparticles in proton therapy"*, (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 (70)

6 ***Researcher(s):***
Alessandro de Angelis (5), Bernardo Tomé (10), Jorge Sampaio (70), Luisa Arruda (80), Marco Alves Pinto (90), Pedro Assis (10)

1 ***PhD Student(s):***
Ana Luisa Casimiro (100)

3 ***Master Student(s):***
Filipe Maximo (49), Luís Sintra (100), Pedro Moreira (84)

1 ***External collaborator(s):***
Elsa Susana Fonseca

Total FTE:
6.7

Articles in international journals:
3 Direct contributions
International conferences:
4 Oral presentations
2 Posters
National conferences:
1 Oral presentation
International meetings:
3 Oral presentations
Advanced Training Events:
3 Oral presentations
Seminars:
1 Seminar
11 Outreach seminars
Completed theses:
1 PhD
2 Masters

Executive summary

In the past 16 years, an area of research and development focused on the study of the radiation environment in space and of its effects was created 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:

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.

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
Patrícia Gonçalves	ESA/4000115004/15/NL/RA/ZK	80.116 €	2015-11-13 / 2019-12-31	Flight Data Analysis of TDP8 Radiation Experiments On-board AlphaSat

Total: 380.116 €

Space Rad

Lines of work and team organization

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 flight model is scheduled to be ready delivered in December 2020. 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 o the radiation data analysis RADEM detector heads calibration and response and on the TID testing of the RADEM custom made ASICS.

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 from the last 6 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.

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. The ongoing work in this subject consists on the upgrade of dMEREM, its validation with data from Mars Curiosity Rover radiation detector (RAD), and on its use in assessing radiation hazards in 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 and co-supervises a master thesis related with the MFS data analysis. She is also responsible for dMEREM update and its validation with data from RAD. Jorge Sampaio co-supervised the work of Ana Luisa Casimiro, in particular in what concerns the effects of radiation on crews and dosimetry until last December and he 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. He supervised a master thesis on an exploratory topic for the Development of an in-flight EEE component test system with integrated radiation monitoring for TID measurement. Patrícia Gonçalves coordinates the Group and is the supervisor of the group Master and PhD thesis at IST.

Stated objectives for past year

The critical objectives were the participation in the instrument development and science teams for planetary missions (to Mars, Jupiter or the Moon); the exploitation and development of installations for radiation tests in Portugal 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. 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 important guidelines for these efforts. In 2019 the group had the following ongoing actvities:

- **The RADEM** tests and calibration of its Engineering Model. To participate in the JUICE mission Science Working Group. Marco Pinto´s PhD completion.
- **The MFS and CTTB Data Analysis** were expected to be continued via a Contract Change Notice already issued to ESA for 2019.
- Validation of the **Geant4** based **Mars Radiation Environment Model (dMEREM)** with data from the RAD, the radiation monitor aboard Curiosity on the Martian surface. Using dMEREM to study the effect of the energetic particle radiation in manned missions to Mars (Ana Luisa´s Casimiro PhD thesis work) and the application of dMEREM to subsoil dose calculation, human spaceflight and astrobiology

The group was preparing for the following activities/calls/projects

- **Preparation of a proposal for the H2020-SPACE-2018-2020 call "Space weather",** as part of an international consortium. The "PREPARE4Moon" project had the objective of Predicting the Energetic Particle Environment at the Moon and the SpaceRad group participation would be to characterise the particle radiation environment on the Moon by developing a model for the lunar radiation environment. The proposal was not approved, but the consortium agreed to keep in-touch for future work. A workshop on "Space Weather science & services in support of lunar missions" organized by Bira, the prime partner of the project proposal, will be held in Brussels in March 2020.
- **Collaboration with the Dosimetry Group**: the LIP Dosimetry Group was starting to work in the development of microdosimeters aimed at supporting proton therapy, for which a facility is foreseen to be built in Lisbon at the Nuclear and Technological Campus of IST. 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.
- **Collaboration with the i-Astro research group:** In 2018 ESA has opened a call for Fast Track Missions, for which a proposal for a smaller and lighter version of e-Astrogam, All-Sky-Astrogam, was being prepared, with A. de Angelis as PI. This proposal passed the first stage of approval for the ESA Fast Missions call, but it was not approved in the final selection in 2019.

Achievements and responsibilities during the past year

Contractual responsibilities and achievements

The main responsibilities and achievements of the group concerned the coordination at LIP of the contracts RADEM, MFS Data Analysis and CTTB Data Analysis together with the Mars radiation environment studies with the Geant4 based dMEREM model.

The **RADEM Directional Detector** studies and tests that were presented in the previous RADECS conference poster session were published, with the title "Development of a Directionality Detector for RADEM, the Radiation Hard Electron Monitor aboard the JUICE Mission" in IEEE Transactions in Nuclear Science journal. The beam tests so far performed with RADEM EM model were presented as a poster at Vienna Conference on Instrumentation with title "Beam test results of the RADEM Engineering Model" and published at Nucl. Instrum. & Methods A.

The **CTTB** simulation was implemented making direct use of the GUIMESH tool to import the geometry from CAD. It was extensively used to predict the accumulated dose for the RADFETs up to July 2018 and compare with the measured values. This study was presented as a poster in RADECS 2019 conference and submitted for publication in the IEEE Transactions in Nuclear Science journal with the title "Dose measurements and simulations of the RADFETs response onboard the ALPHASAT CTTB experiments".

The **MFS data analysis** was subject to a verification of the corresponding Geant4 simulation application leading to an update of the MFS proton and electron response functions. Studies towards a new unfolding method to extract the measured particle fluxes was initiated in the context of the Master thesis of L. Sintra. F. Máximo successfully finished his thesis of the analysis of MFS data using an unfolding method based on a maximum likelihood fit to data.

The **dMEREM simulation tool** was updated and improved. The Geant4 physics models used to describe the hadronic interactions were benchmarked with proton fluxes measured at Mars surface by the RAD detector aboard the NASA Curiosity rover. dMEREM was validated with RAD measured data during September 2017 Solar Event and with cosmic ray data acquired by RAD.

The **GUIMesh tool** developed during 2017 and 2018 that provides an easy to use and fast methodology to introduce complex geometries in Geant4, and has been a very important development for the ongoing projects such as RADEM and the MFS data analysis was made available to the scientific community in Github and has been highly requested. The description of the tool performance and use was published in Computer Physics Communications.

Training

- Marco Pinto finished his PhD thesis on RADEM in July 2019
- Ana Luisa Casimiro successfully presented her PhD thesis work in May 2019 to the thesis CAT commission. Unfortunately, due to health constraints, the PhD programme of Ana Luisa was cancelled in December 2019.
- Two students (Filipe Maximo and Pedro Moreira) finished their Master theses during 2019, and another student (Luís Sintra) started his master thesis in February 2019.

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, and the exploitation and development of installations for radiation tests in Portugal 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. 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 two years period from the beginning of 2020 to the end of 2021 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 October 2020. 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** 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 5 years of scientific data to be analysed. A new unfolding method for the MFS measured fluxes will be developed by L. Sintra in his thesis work. MFS scientific data will be extensively analysed. Radiation effects on the CTTB components during the 5 years of data collection will continue to be studied.
- The activities concerning the exploration of the **Geant4** based **Mars Radiation Environment Model** will continue. On one side the validation of the Mars model with real data will be carried on and the underground radiation environment will be accessed to predict possible existence of conditions for life. 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.

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 ProtoTerra 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.

Also in the framework of the collaboration with the LIP Dosimetry and OR Imaging groups, a proposal was prepared to the UTAustin Portugal Program 2019 Call for Exploratory Proposals in January 2020, regarding FLASH radiotherapy.

- **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, and that is hopefully a first step towards a network at Técnico for space S&T, putting together people from different areas, from astrobiology to space systems and robotics, including, of course, space radiation environment and effects. Patrícia Gonçalves has also been actively involved in the team that is organizing the "Space Seminar Series" (S^3), which will be a monthly multi-disciplinary seminar series open to everybody, including students, researchers and staff members interested in space sciences and technology. The S^3 will include world-renowned international invited speakers, who will present the latest research in the field and a preview of the future of space science".

- **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, a group of experts is being created to advise the PT-Space agency on this subject, of which Patrícia Gonçalves is a member.

Activities in preparation

The group is currently preparing for the following activities/calls/projects

- **Proposal to the FCT call for projects in all scientific domains** (PTDC) 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. The model will be used 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 will 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 will include dMEREM subsurface predictions, which can be applied to astrobiology studies.
- **Proposal to the "Scientific Data Exploitation" SPACE-30-SCI-2020 call**: the proposal will address the problem of data unfolding for particle data collected by the Galileo and Cassini missions , which will enable to attain a better understanding on the properties of energetic particle spectra, particularly in the MeV range, surrounding the gas giants. This project will provide valuable input for the preparation of the RADEM in-data analysis campaign. This proposal involves scientists at the Max Plank institute, at the University of Athens and at SPARC, a Greek PME.

Theses

- Luís Sintra will finish his master thesis by the end of the 1st semester of 2020
- Several master thesis subjects were announced for Engineering Physics students ate IST and to Physics and Engineering Physics students at FCUL.

Medium-term (3-5 years) prospects

For the period 2023 to 2025 the Group expects to:

- Be involved in the next phases of the **RADEM detector development,testing and deployment**, including RADEM in-flight testing in the Earth orbit – for which flight opportunities have to be sought – 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 both during the cruise phase and during the Jovian phase. In the first case the data will contribute to a better understanding of the heliospheric radiation environment, while data from the Jovian phase, namely data collected around the Jovian Icy Moons , will be valuable for different studies, such as of atmosphere creation processes and astrobiology studies.
- 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 spaceweather.
- Strengthen the interdisciplinary collaboration with groups working on space science and technology at the Lisbon University.
- Reinforce the collaboration with the Dosimetry group, in what concerns the involvement in the future Prototherapy Centre and in the National Prototherapy Network – ProtoTera.

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 Geant4DNA 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.
- 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 can 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

Weaknesses

- In terms of funding the group heavily depends on contracts with the European Space Agency which a typical duration between 1 year to 3 years. Two contracts finished during 2019.
- 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.

Threats

- National project calls have been unpredictable both in what concerns opening dates, publication of results and replies to requests of review.
- 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 or possible periods with no founding.
- Constant networking effort and attention to ESA intended and published invitation to tender calls is required.
- 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.
- To plan for this activity as a service oriented activity only, when the scientific potential can be exploited.

Publications

3 Articles in international journals

(with direct contribution from the team)

- *"GUIMesh: a tool to import STEP geometries into Geant4 via GDML"*, M. Pinto, P. Gonçalves, Computer Physics Communications, Volume 239, June 2019, Pages 150-156,10.1016/j.cpc.2019.01.024
- *"Development of a Directionality Detector for RADEM, the Radiation Hard Electron Monitor aboard the JUICE Mission"*, M. Pinto, P. Gonçalves, W. Hadjas, A. Marques , J. Costa Pinto, IEEE Transactions on Nuclear Science Volume: 66 Issue: 7 ,1770 - 1777, 10.1109/TNS.2019.2900398
- *"Beam test results of the RADEM Engineering Model"*, M.Pinto, P. Gonçalves, P. Socha, W. Hajdas, A. Marques, J.Costa Pinto , Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Space Rad

Presentations

4 Oral presentations in international conferences

- Ana Luisa Casimiro : *"Validation of Geant4 model based predictions of radiation hazards in manned missions to Mars with the RAD/MSL data"*, 2019-05-31, 3rd International Conference on Dosimetry and its Applications (ICDA3) 27-31 May 2019, IST, Lisbon
- Marco Alves Pinto: *"Total Ionizing Dose estimation and response of ASIC VATA466 to be flown in RADEM aboard the JUICE mission"*, 2019-05-31, 3rd International Conference on Dosimetry and its Applications (ICDA3) 27-31 May 2019, IST, Lisbon
- Marco Alves Pinto: *"Beam tests of a prototype of the Radiation Hard Electron Monitor to be flown in the JUICE mission"*, 2019-10-15, 15th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD19) , Siena, Italy
- : *"Particle Physics Technologies applied to Space"*, 2019-10-16, IEEE 45 Annual Conference of the Industrial Electronics Society -.2019 Women in IES Forum in Europe, Lisbon

2 Poster presentations in international conferences

- Marco Alves Pinto: *"Beam test results of the RADEM Engineering Model"*, 2019-02-21, 15th Vienna Conference on Instrumentation, 18-22 February 2019, Vienna, Austria
- Jorge Sampaio: *"Dose measurements and simulations of the RADFETs response onboard the ALPHASAT CTTB experiments,"*, 2019-09-18, RADECS 2019, 16th-20th September 2019, Montpellier, France

3 Oral presentations in international meetings

- Patrícia Gonçalves: *"Astrobiology studies with the ESA detailed Mars Energetic Radiation Environment Model and GSI data"*, 2019-05-21, International Biophysics Collaboration Meeting,GSI/FAIR, Darmstadt, Germany
- Jorge Sampaio: *"High resolution dosimetry R&D at LIP for medical and space applications "*, 2019-05-21, International Biophysics Collaboration Meeting,GSI/FAIR, Darmstadt, Germany
- Marco Alves Pinto: *"GUIMesh: a tool to import STEP geometries into Geant4 via GDML"*, 2019-10-21, 14th Geant4 Space Users Workshop, Xylokastro, Greece, 20-23rd October 2019., Xylokastro, Greece

1 Presentations in national conferences

- Patrícia Gonçalves: *"Participação Científica em Futuras Missões Espaciais "*, 2019-07-08, Ciência 2019, Centro de Congressos de Lisboa

3 Oral presentations in Advanced Training events

- Beatriz Ferreira: *"Measuring radiation effects in Space"*, 2019-02-05, LIP summer student Programme 2018 - nal Workshop , LIP, Lisboa
- Patrícia Gonçalves: *"From Earth to Jupiter From Particle Physics to Space"*, 2019-02-11, Fourth Lisbon mini-school on Particle and Astroparticle Physics, Costa da Caparica
- Luisa Arruda: *"Radiação de origem cósmica"*, 2019-07-08, Workshop Hands on Particles and Light for Life, IST, Lisbon

1 Seminars

- Marco Alves Pinto: *"Radiation challenges and perspectives for the ESA JUICE mission"*, 2019-07-04, LIP seminar, LIP, Lisbon

11 Outreach seminars

- Luisa Arruda: *"Space activites / ESA"*, 2019-02-28, Inside Views, LIP, Lisbon
- Patrícia Gonçalves: *"Tomografia de Muões e Marte? "*, 2019-07-31, HACKATHON – CORRIDA A MARTE NO LOUSAL, Centro Ciência Viva do Lousal, Lousal
- Marco Alves Pinto: *"A bordo da missão JUICE"*, 2019-10-08, O Espaço Vai à Escola, ESERO, Ciência Viva, Colégio Guadalupe, Aroeira
- Marco Alves Pinto: *"Para o Espaço e mais além!"*, 2019-10-08, O Espaço Vai à Escola, ESERO, Ciência Viva, Externato Cinderela, Amadora
- Patrícia Gonçalves: *"Do Sol à Terra e da Terra a Marte e à Lua"*, 2019-10-09, O Espaço Vai à Escola, ESERO, Ciência Viva,
- Marco Alves Pinto: *"A bordo da missão JUICE"*, 2019-10-10, O Espaço Vai à Escola, ESERO, Ciência Viva, CED Nuno Álvares Pereira, Lisboa
- Marco Alves Pinto: *"A bordo da missão JUICE"*, 2019-10-11, O Espaço Vai à Escola, ESERO, Ciência Viva, Escola Secundária Rainha Dona Amélia, Lisboa
- Marco Alves Pinto: *"A bordo da missão JUICE"*, 2019-10-11, O Espaço Vai à Escola, ESERO, Ciência Viva, Colégio S. João de Brito
- Luisa Arruda: *"Raios Cósmicos - um desafio para as viagens espaciais!"*, 2019-10-17, O Espaço Vai à Escola, ESERO, Ciência Viva, Escola Secundária José Gomes Ferreira, Benfica, Lisboa
- Jorge Sampaio: *"Da Terra ao Espaço - O desafio radiológico"*, 2019-10-29, O Espaço Vai à Escola, ESERO, Ciência Viva, Escola Secundária Luís de Freitas Branco, Paço de Arcos
- Marco Alves Pinto: *"A bordo da missão JUICE"*, 2019-11-05, O Espaço Vai à Escola, ESERO, Ciência Viva,, Escola Secundária Rainha Dona Amélia, Lisboa

Theses

1 PhD

- Marco Alves Pinto: ***"Development of a Directionality Detector and Radiation analysis for RADEM, a RADiation hard Electron Monitor for the JUICE mission"*,** 2015-02-01 / 2019-07-25, (finished)

3 Master

- Filipe Maximo: *"Analysis of in-flight data on the AlphaSat radiation Environment Effects Facility"*, 2016-09-01 / 2019-06-27, (finished)
- Pedro Moreira: *"Development of an in-flight EEE component test system with integrated radiation monitoring for TID measurement "*, 2018-09-01 / 2019-11-28, (finished)
- Luís Sintra: *" Particle Energy Spectra Reconstruction of the Multi-Functional Spectrometer In-flight Data using Machine Learning Techniques"*, 2018-12-03 , (ongoing)

I-ASTRO

Space Instrumentation for Astrophysics

Principal Investigator:
Rui Curado Silva (85)

6 ***Researcher(s):***
Alessandro de Angelis (5), Filomena Santos (10), Jorge Maia (45), José Escada (20), Marco Alves Pinto (10), Teresa Dias (15)

2 ***PhD Student(s):***
Alexandre Fonseca Trindade (30), Miguel Moita (100)

1 ***Master Student(s):***
Joana Mingacho (33)

2 ***Undergraduate Student(s):***
Giorgio Canezin, Henrique Neves

1 ***External collaborator(s):***
André Cortez

Total FTE:
3.5

Articles in international journals:
3 Direct contributions
Proposals, Yellow reports and related studies:
2
Internal notes:
1 Note
International conferences: 5
Oral presentations
5 Posters
2 Proceedings
National conferences:
2 Poster
International meetings:
4 Oral presentations
Seminars:
1 Seminar
8 Outreach seminars
Completed theses:
1 PhD
Organized events:
1 International Conferences or Workshops
2 Outreach events

Executive summary

The Space Instrumentation for Astrophysics Group (i-Astro) develops its research activities in the framework of mission proposals to ESA and NASA in the X- and gamma-ray domain. The group is part of AHEAD2020 (Activities in the High Energy Astrophysics Domain) H2020 project as well as of AMEGO (All-sky Medium Energy Gamma-ray Observatory) and IXPE (Imaging X-ray Polarimetry Explorer) space missions consortia. Our group is contributing to the development of detection plane 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.

In 2019, in the framework of AHEAD WP9 (Work Package 9), entitled "Gamma-ray experiments", e-ASTROGAM and AMEGO instrument mass models were simulated and its polarimetric performances were assessed. Polarimetric measurements with a double layer CdTe prototype under a polarized beam at the ESRF (European Synchrotron Radiation Facility) and at LARIX (LARge Italian X-ray facility) facility at the University of Ferrara. Progressing from WP9 in former AHEAD, in the new AHEAD2020 EU funded project our group will take part in 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.

Research activities underline the project ProtonRadCdTe (Protons Radiation Hardness in CdTe Detectors for Space Instrumentation), were carried on. The project 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. We contributed to analyze of the proton radiation sensitivity of CdTe detectors, using a low MeV range proton radiation field, generated in a cyclotron facility. 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.
We kept contributing to the development of the main instrument of NASA IXPE mission, by simulating the potential polarimetric performances of different noble gases: Xe, Ar, Ne and He.

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

Lines of work and team organization

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) IXPE mission.

1 - In AHEAD2020 our group will contribute to COMCUBE demonstrator and AMEGO mission developments. R. Curado da Silva coordinates the participation in both projects.

1.1- We will take part in the development of COMCUBE demonstrator design and simulation tasks. The detector simulation is part of Henrique Neves Master thesis under the supervision of J. Maia and R. Curado 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 M. Moita and G. Canezin, under the supervision of R. Curado da Silva and F. Santos.

2 - The ProtonRadCdTe project with the goal of evaluation of the proton radiation hardness in CdTe detectors in context of a LEO mission continued under the coordination of J. Maia.

2.1- Complement the proton radiation sensitivity measurements with CdTe detectors, using protons beams within the energy band, 1−14 MeV.

2.2- Develop an optimal proton irradiation strategy that best suits the missions' requirements: select a range of energy for the protons that is potentially more relevant in the context of the intensity of the damage produced, and of the nuclear activation in material.

3 - The IXPE scientific payload is composed by a mirror assembly and a focal plane instrument based on GPD (Gas Pixel Detector) X-ray polarimeter. GPD gas mixture optimization tasks are part of J. Escada and A. Trindade PhD thesis, under the supervision of R. Curado da Silva and J. Maia.

3.1- GPD gas mixture simulation is performed by J. Escada, under the supervision of J. Maia and of R. Curado da Silva.

3.2- GPD gas mixture testing will be performed by A. Trindade under the supervision of F. Santos and J. Maia.

Stated objectives for past year

The objectives for the past year divided by lines of work: 1) AHEAD; 2) ProtonRadCdTe; and 3) IXPE:

1- H2020 AHEAD project ended February 2019. Submit a second AHEAD H2020 Project, in particular gamma-ray space instruments with the same partners on two new mission concepts.

1.1- Submission of AHEAD 2 proposal to Integrating Activities for Advanced Communities H2020 Call (INFRAIA-01-2018-2019) by March 22nd, 2019;

1.2 – Test double layer CdTe polarimeter prototype under a gamma-ray beam up to 300 keV at LARIX facility. Perform Laue lens response measurements under the LARIX beam;

1.3 – Submit All-Sky-ASTROGAM Phase-2 proposal by March 20th, 2019. Unfortunately, All-Sky-ASTROGAM mission was not selected for launch by ESA;

1.4 – Contribute to AMEGO white papers concerning the scientific polarimetric potential of the mission, performing mass model simulations with MEGAlib simulation tool. These white papers were submitted to NASA Decadal Survey during 2019.

2- In ProtonRadCdTe project, evaluation of the proton radiation sensitivity of ohmic CdTe detectors, using a low MeV range proton radiation field, a complementary LEO proton energy spectrum profile.

3- Optimize IXPE mission GPD gas mixture and develop of an experimental system to measure electron cloud diffusion.

Achievements and Responsibilities during the past year

- AHEAD2020 European project proposal was selected for funding for 4 years and will start the March 1st, 2020. LIP activities in WP11 will be funded at 30 k€, but further funding will be available for testing in any of AHEAD facilities.
- In the framework of AMEGO instrument mass model were simulated under different polarized gamma-ray source emissions. One communication was presented at the INTEGRAL Workshop 2019, Geneva and published a paper on Experimental Astronomy journal. Three white papers where elaborated and published in the arXives and in the The Bulletin of the American Astronomical Society;
- A double layer CdTe detector prototype operating together with a Laue lens crystal system, was tested under a polarized beam at the LARIX beam. The results obtained confirmed the potential of multilayer focal plane operating in the focal plane of a Laue lens system. One communication was presented at the 2019 IEEE Nuclear Science Symposium, Manchester, UK.
- The STRATOSpheric POLarimetry with Cadmium Telluride Array (STRATOSPOLCA) experiment was selected for launch in ESA BEXUS balloon call.
- In ProtonRadCdTe project the data analysis of the radiation effects on CdTe detectors were finished. The CdTe detectors showed a low proton radiation sensitivity for the proton energy band and within the total fluence range studied. An article was published in the IEEE Trans. Nucl. Sci. journal.
- The polarimetric performances of several noble gases (Xe, Ar, Ne and He), alone, in combined mixtures as well as with additives, were simulated for IXPE GPD instrument. A publication is being prepared where each gas filling solution will be analyzed.

Lines of work and objectives for next year

The objectives of the main lines of work, 1) AHEAD, 2) ProtonRadCdTe and 3) IXPE, for 2020 are: 1- The new AHEAD2020 project will start the March 1st, 2020. AHEAD WP11 activities will focus in a Cubesat-compatible Compton telescope demonstrator and will support our participation in ESA BEXUS program and on AMEGO NASA proposal.

1.1- i-Astro will take part in the first task of AHEAD2020 WP11, in particular we will participate in the design and mass model simulation of the Si DSSD tracker (double-sided silicon strip detector) and of the calorimeter scintillator detector. The objective of this task is to optimize the instrument configuration - detector geometry, sensitive and material, etc.;

1.2 – In the framework of AMEGO proposal development, i-Astro will contribute to mass model simulations with MEGAlib simulation tool. Furthermore, a small size prototype experiment is schedule for this summer 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 energyrange. Afterwards, further prototype development is envisaged in order to set a balloon born prototype testing, at ~40 km, that will likely take place at the beginning of 2021.

1.3 – The STRATOSPOLCA experiment will be launched in an ESA BEXUS program balloon platform from Kiruna, Sweden by October 2020. 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 project our group will continue the evaluation of the proton radiation hardness in CdTe detectors exposed to a complementary proton energy band from 14 to 50 MeV, to best mimic the LEO proton energy spectrum, given the expected additional role in the nuclear activation and thus in gamma-ray background and neutron damage effects within the CdTe crystal as well as the mild role in proton damage effects.

3 - In IXPE mission collaboration our group has the task to find the best trade-off gas mixture, between lowest electron diffusion in the gas and the highest possible electron drift speed. The simulation code will be improved to include quenching additive gases like DME and isobutane gases with the noble gases already studied. Furthermore, an experimental system was assembled. Laboratorial measurements will be performed in order to measure electron cloud diffusion and these results will be compared with the mentioned simulations.

Medium-term (3-5 years) prospects

i-Astro 2020-25 research plan consists on the development of innovative concepts to address high-energy astrophysics most relevant issues within 3 mission proposals: COMCube, AMEGO and IXPE. In the new 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 supporting such low-cost platforms for space science missions. This work package WP11 ("Space Experiments for HE Astrophysics & Multi-messenger Astronomy") will allow to set a new gamma-ray mission proposal based on cubesat platforms. We expect that AMEGO mission, will be selected by NASA in the next Probe-Class call. In the framework of AMEGO we will contribute to develop the first laboratorial prototype and space instrument capable to perform pair-production regime polarimetric measurements as well as optimal high-energy Compton polarimetry, providing a wider gamma-ray polarimetry window (up to ~30 MeV) with a vast scientific potential in high-energy astrophysics. Continue to work in the framework of the ProtonRadCdTe project. Develop a proton irradiation strategy that best suits the purpose of the tests to be performed: select a range of energy for the protons that is potentially more relevant in the context of the intensity of the damage produced, and in the context of nuclear activation in material. Furthermore, the results of the tests of the effects of orbital radiation on the detector, may be important for the conclusions regarding the optimal configuration and mode of operation of future CubeSat solutions. IXPE was selected for NASA SMEX Call due to its great innovative polarimetric potential in the X-ray domain (2 - 8 keV). IXPE will be the first photoelectric regime polarimeter that will operate in space, opening a new scientific window on the hard X-ray astrophysics domain. Our contribution consists the development of a new gas mixture for the main instrument X-ray detector.

We will keep applying to ESA and NASA balloon and CubeSat scientific experiment calls for students in order to contribute to our young future researchers acquire advanced learning in space or quasi-space environment technology.

SWOT analysis

Strengths and Opportunities

The group is a partner of three major international projects in high-energy astrophysics: AHEAD2020 European project, AMEGO and IXPE NASA missions. Our participation in these consortia is the consequence of our expertise on high-energy astrophysics polarimetry for more than one decade, both by simulation 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 project ProtonRadCdTe provides an opportunity to apply the same methods and techniques of space instrumentation development to orbital missions.

Weaknesses and Threats

The level of collaboration with industry is still weak, however there is an agreement with space related companies to collaborate in the next call for projects, specially PRODEX space-oriented call. Collaboration in the framework of student training in collaboration with company has been already established with Active Space company and further future student thesis will include collaboration with this and other companies. Last decade lack of national funding has compromised seriously equipment acquisition, as well as the number of grants and contracts available for young researchers as well as senior researchers as the group responsible.

i-Astro

Publications

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

- *"Compton polarimetry with a multi-layer CdTe focal plane prototype"*, M. Moita, E. Caroli, J.M. Maia, R.M. Curado da Silva, N. Auricchio, J.B. Stephen, M. Páscoa, A.M.F. Trindade, Nucl. Instr. Meth. A, Vol. 918, 2019, pp. 93-98
- *"Future gamma-ray missions' polarimetric prospects"*, A. F. V. Cortez et al., Exp. Astron. 48 (2019) 65-76
- *"Orbit-Like Proton Radiation Sensitivity of CdTe Detectors: Evaluation of Mobility-Lifetime Products and Spectroscopic Properties"*, M. P. Pascoa, J. M. Maia, N. Auricchio, R. M. Curado da Silva, P. Crespo, S. J. C. do Carmo, M. Moita, F. Alves, E. Caroli, IEEE Trans. Nucl. Sci. 66 (2019) 2063-2071

1 Internal Notes

- Bindu Rani, H Zhang, SD Hunter, F Kislat, M Böttcher, JE McEnery, DJ Thompson, D Giannios, F Guo, H Li, M Baring, I Agudo, S Buson, M Petropoulou, V Pavlidou, E Angelakis, I Myserlis, Z Wadiasingh, RM da Silva, P Kilian, S Guiriec, VV Bozhilov, J Hodgson, S Antón, D Kazanas, P Coppi, T Venters, F Longo, E Bottacini, R Ojha, B Zhang, S Ciprini, A Moiseev, C Shrader: ***"High-Energy Polarimetry-a new window to probe extreme physics in AGN jets",*** arXiv preprint arXiv:1903.04607

2 International Conference Proceedings

- *"Prompt Emission Polarimetry of Gamma-Ray Bursts"*, Mark McConnell, Marco Ajello, Matthew Baring, Peter Bloser, Tanmoy Chattopadhyay, RMC da Silva, Sylvain Guirec, Dieter Hartmann, Hui Li, Alex Lowell, Chanda Prescod-Weinstein, Bindu Rani, Vincent Tatischeff, John Tomsick, Alexander van der Horst, Tom Vestrand, Zorawar Wadiasingh, Silvia Zane, Bing Zhang, Haocheng Zhang, Astro2020: Decadal Survey on Astronomy and Astrophysics, science white papers, no. 100; Bulletin of the American Astronomical Society, Vol. 51, Issue 3, id. 100 (2019)
- *"All-Sky-ASTROGAM - The MeV Gamma-Ray Companion to Multimessenger Astronomy"*, A. De Angelis, V. Tatischeff, M. Mallamaci*, R. Rando, M. Tavani, U. Oberlack, R. Walter, G. Ambrosi, A. Argan, P. von Ballmoos, D. Bastieri, E. Bernardini, S. Brandt, A. Bulgarelli, A. Bykov, V. Fioretti, I. Grenier, L. Hanlon, D. H. Hartmann, M. Hernanz & 16 others G. Kanbach, I. Kuvvetli, P. Laurent, M. Mariotti, M. N. Mazziotta, J. Mc Enery, S. Mereghetti, A. Morselli, K. Nakazawa, M. Pearce, E. Prandini, J. Rico, R. Curado da Silva, X. Wu, A. Zdziarski, A. Zoglauer, P o S - Proceedings of Science, 358, [579].

2 Proposals, Yellow Reports and related documents

- *"ESA F-class mission proposal: All-Sky-ASTROGAM - The MeV Gamma-Ray Companion to Multimessenger Astronomy"*, All-Sky-Astrogam Collaboration,
- ***"All-sky Medium Energy Gamma-ray Observatory: Exploring the Extreme Multimessenger Universe",*** Julie McEnery and AMEGO collaboration, arXiv:1907.07558 [astro-ph.IM]

Presentations

5 Oral presentations in international conferences

- José Escada: *"Monte Carlo Simulation of X-ray Polarization Sensitivity in Noble Gas/Methane Mixtures"*, 2019-10-17, SXSDG 2019 - 2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application, Physics Department - Coimbra University
- Rui Curado Silva: *"AHEAD2020 project prospects for High-Energy Astrophysics"*, 2019-10-17, 2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application, Departamento de Física, Universidade de Coimbra
- Miguel Moita: *"Polarimetric performance of a multilayer CdTe spectro-imager for high-energy astrophysics"*, 2019-10-18, SXSDG 2019 - 2nd International Workshop , Physics Department - Coimbra University
- Jorge Maia: *"Proton Radiation Sensitivity of Gamma-Ray CdTe Detectors"*, 2019-10-18, SXSDG 2019 - 2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application, Physics Department - Coimbra University
- Miguel Moita: *"Polarimetric performance of a Multilayer CdTe Spectro-imager for High-energy Astrophysics"*, 2019-10-30, 2019 IEEE Nuclear Science Symposium and Medical Imaging Conference, Manchester, UK

5 Poster presentations in international conferences

- Giorgio Canezin: *"High-energy Future Space Telescopes Source Sensitivity in the Multi-Messenger Era"*, 2019-10-18, 2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application, Universidade de Coimbra
- Joana Mingacho: *"Terrestrial Gamma-Ray Flashes Analysis for Aircraft Transport Safety"*, 2019-10-18, 2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application, Universidade de Coimbra
- Henrique Neves: *"Compton CubeSat Prototype"*, 2019-10-18, 2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application, Universidade de Coimbra
- Alexandre Fonseca Trindade: *"2nd International Workshop on Soft X-ray Single Order Diffraction Grating Development and Application"*, 2019-10-18, SXSDG 2019 - 2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application, Physics Department - Coimbra University
- Miguel Moita: *"Study of Bent Crystals Response for an Hard X-Ray Laue Lens with a Pixel CdTe Detector"*, 2019-10-30, 2019 IEE Nuclear Science Symposium and Medical Imaging Conference, Manchester, UK

4 Oral presentations in international meetings

- Rui Curado Silva: *"Polarimetry in Gamma-ray Astronomy"*, 2019-02-13, 12th INTEGRAL Workshop and 1st AHEAD Gamma-ray workshop, INTEGRAL looks AHEAD to Multi-Messenger Astrophysics, Geneva, Switzerland.
- Rui Curado Silva: *"Future gamma-ray mission's polarimetric prospects"*, 2019-05-15, Multi-messenger astronomy with SKA precursors and path nders, a capacity building workshop, Instituto Telecomunicações, Campus Universitário de Santiago, Aveiro, Portugal
- Alessandro de Angelis: *"Gamma-ray astronomy in context"*, 2019-05-15, Multi-messenger astronomy with SKA precursors and path nders, a capacity building workshop, Instituto Telecomunicações, Campus Universitário de Santiago, Aveiro, Portugal
- Henrique Neves: *"STRATOSPOLCA - STRATOSpheric POLarimetry with Cadmium Telluride Array"*, 2019-11-28, BEXUS - Selection Workshop, ESA/ESTEC, Noordwijk, Holanda

2 Poster presentations in national conferences

- José Escada: *"Monte Carlo Simulation of X-ray Polarimetry in Noble Gas/Methane Mixtures"*, 2019-09-12, XXIX Astronomy and Astrophysics National Meeting, Centra - Instituto Superior Técnico, Lisboa, Portugal
- Miguel Moita: *"Polarimetric performance of a multilayer CdTe spectro-imager for high-energy astrophysic"*, 2019-09-12, XXIX Astronomy and Astrophysics National Meeting, Centra - Instituto Superior Técnico, Lisboa, Portugal

1 Seminars

- Rui Curado Silva: *"High-Energy Space Observatories in the New Era of Multi-Messenger Astrophysics"*, 2019-03-06, Café com Física, Departamento de Física, Universidade de Coimbra

8 Outreach seminars

- Rui Curado Silva: *"Aquecimento Global Consequências e Soluções"*, 2019-03-08, , Escola Secundária Marquesa de Alorna, Almeirim
- Rui Curado Silva: *"Aquecimento Global Consequências e Soluções"*, 2019-04-03, , Escola Básica e Secundária Dr. Manuel R. Ferreira, Alvaiázere
- Rui Curado Silva: *"Como Ser Astronauta"*, 2019-04-05, , Escola Nery Capucho, Marinha Grande
- Rui Curado Silva: *"High-Energy Space Observatories in the New Era of Multi-Messenger Astrophysics"*, 2019-04-23, BEST (Board of European Students of Technology) Space Day, Departamento de Física, Universidade de Coimbra
- Rui Curado Silva: *"Futuro da Exploração Espacial 50 anos depois da Apollo XI"*, 2019-05-15, , Departamento de Física, Universidade de Coimbra
- Rui Curado Silva: *"Futuro da Exploração Espacial 50 anos depois da Apollo XI"*, 2019-06-03, , Escola Eugénio de Castro, Coimbra
- Rui Curado Silva: *"Aquecimento Global Consequências e Soluções"*, 2019-06-27, , Escola Técnica e Profissional do Ribatejo
- Rui Curado Silva: *"Astronomia & Tecnologia Espacial no Quotidiano"*, 2019-09-12, Portugal Space Summer School , Observatório Astronómico da Universidade de Coimbra e Dep. de Física da UC

Organized Events

1 International Conferences or Workshops

- *"2nd International Workshop on Soft X-ray Single-order Diffraction Grating Technology and Application"*, Universidade de Coimbra, 2019-10-16 to 2019-10-20

2 Outreach Events

- *"Escola de Verão - 'Como ser Astronauta'"*, [OutR] 2019-07-15 / 2019-07-19, Universidade de Coimbra e Observatório Astronómico da UC
- *"Portugal Space Summer School"*, [OutR] 2019-09-11 / 2019-09-13, Universidade de Coimbra e Observatório Astronómico da UC

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)

1 Master

- Joana Mingacho: *"Terrestrial Gamma-ray Flashes analysis for Aircraft Transport Safety"*, 2019-09-01 , (ongoing)

Computing

[Scientific Computing]

GRID
Advanced Computing
SPAC

GRID

Distributed Computing and Digital Infrastructures

Principal Investigator:
Jorge Gomes (100)

4 ***Researcher(s):***
Gaspar Barreira (37), João Paulo Martins (100), João Pina (100), Mário David (100)

7 ***Technician(s):***
Carlos Manuel (100), Dinis Monteiro (100), Henrique Carvalho (50), Hugo Gomes (100), José Aparício (100), Nuno Ribeiro Dias (100), Samuel Bernardo (100)

1 ***Trainee(s):***
Diana Maria Naranjo Delgado

5 ***External collaborator(s):***
André Vieira, Catarina Ortigão, Isabel Campos, João Machado, Zacarias Benta

Total FTE:
10.9

Articles in international journals:
1 Direct contribution
Internal notes:
12 Notes
International conferences:
11 Oral presentations
1 Poster
2 Proceedings
National conferences:
3 Oral presentations
1 Proceeding
International meetings:
2 Oral presentations
Collaboration meetings:
6 Oral presentations
Seminars:
3 Seminars
Organized events:
1 International Conferences or Workshops
Articles in outreach journals:
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, management, advanced training and outreach activities. The group has extensive experience in delivering compute and data oriented services for simulation, data processing and analysis. The services portfolio includes the Portuguese Tier-2 computing 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.

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 distributed data processing using cloud computing, high throughput computing, high performance computing and machine learning. The group is participating in the H2020 projects: EOSC-hub, DEEP-Hybrid-DataCloud, and EOSC-Synergy.

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.

The group activities bridge at international level with science related infrastructures and initiatives such as the European Grid Infrastructure (EGI), Iberian Grid Infrastructure (IBERGRID) and European Open Science Cloud (EOSC). 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 / 2020-07-17	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 / 2020-12-31	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

Total: 1.606.779 €

GRID

Lines of work and team organization

The team activities are organized in four areas:

- Scientific computing and data processing services such as processing farms, cloud computing, online storage, and WLCG Tier-2/Tier-3. Delivery of services to external users in the context of the Portuguese National Distributed Computing Infrastructure (INCD), whose activities have been pioneered by LIP. These services are integrated in international digital infrastructures and initiatives such as EGI, IBERGRID and EOSC.
- Participation in 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, network related technologies, authentication and authorization, virtualization, data repositories, machine learning, software quality assurance and others.
- Core institutional services including support to administrative services, network related services, desktops, laptops, security, authentication and authorization, printers, data protection and others.
- Provisioning of web development, graphics design and multimedia services, supporting outreach, dissemination, exploitation, management and research activities.

These lines of work are 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 projects.

Stated objectives for past year

LIP IT Services

- Improve the services and internal network.
- Reorganize documentation and software repositories.
- Improve authentication and authorization.
- Improve user registration.

WLCG and Tier-2

- Implement new Lustre storage system and batch system.
- Implement WLCG recommendations pending due to the lack of resources.
- Reorganize Tier-2 network taking advantage of new equipment.

INCD

- Execute the INCD P2020 national infrastructure project.
- Improve the INCD cloud, HPC and HTC services.
- Deploy new HPC service equipped with low latency interconnect.
- Establish an INCD point-of-presence in Minho.
- Integrate capacity from the BOB cluster (TACC / FCT).

EGI, IBERGRID and EOSC

- Iberian collaboration in the European Grid Infrastructure (EGI) and IBERGRID.
- Participation in the EOSC-hub project, including development and operation of the OPENCoastS thematic service, and maintenance of the udocker software.
- Start the EOSC-Synergy project aimed at development and adoption of EOSC services.

INDIGO-DC and DEEP-Hybrid-DataCloud

- Continue the DEEP-Hybrid-DataCloud project in the area of large scale deep learning and post-processing in cloud and HPC environments and related software quality assurance.

Achievements and responsibilities during the past year

The LIP group coordinated the INCD technical activities including development and operations. The deployment of the equipment purchased by INCD for the Lisbon center was completed by the LIP team. The equipment funded by the FCT infrastructures roadmap will be used to support the national academic and research community within the FCT advanced computing network, of which INCD is one of the infrastructure providers. In this context the cloud, HPC and HTC services were improved and the software upgraded or redeployed. The INCD network backbone in Lisbon was also fully upgraded.

A new INCD operations center has been established at LIP Minho with INCD staff integrated in the LIP computing group. Through this center, LIP participated together with FCT-FCCN, INCD, and MACC in the deployment of the BOB supercomputer at Minho. This is the largest High Performance Computing facility in the country and is split in two computing partitions currently operated by MACC and INCD. The storage system that serves both partitions was deployed and is managed by the LIP team in Lisbon, while the computing partition allocated to INCD is being managed by the INCD team in LIP Minho. INCD also deployed additional equipment to reinforce the Minho facility.

The Tier-2 and LIP computing farm services established on top of INCD have been improved. In 2019 the Portuguese Tier-2 in the World Wide LHC Computing Grid (WLCG) delivered more than 110,000,000 normalized (HEPSPEC06) processing hours to ATLAS and CMS. The increase of delivered capacity was possible thanks to the new INCD equipment in Lisbon.

The group participated in the EGI governance and technical activities liaising Portugal with this international infrastructure. The IBERGRID collaboration continued providing an umbrella for a common Iberian participation in EGI and EOSC.

The EGI middleware coordination was again performed by LIP, IFCA and CESGA in the context of the IBERGRID collaboration. The 10th IBERGRID conference was held in Santiago de Compostela, it was organized by CESGA, IFCA and LIP and counted with more than 100 participants.

The LIP group participated in the FCT advanced computing work group, in several activities towards the national participation in EuroHPC, namely the European proposal for national competence centers in EuroHPC.

Within the context of the European Commission Open Science Cloud (EOSC), LIP continued the participation in the EOSC-hub project that joins EGI, EUDAT and the INDIGO-DC consortium. Within this project LIP is coordinating the software management activity for all infrastructures federated in EOSC-hub at European level. Also in EOSC-hub, LIP continued to collaborate with LNEC to develop and operate OPENCoastS, a thematic service to deliver wave and ocean circulation forecasts for the European Atlantic coast.

The EOSC-Synergy project started in September 2019 aiming at harmonizing policies and federating relevant national research e-Infrastructures, scientific data and thematic services, bridging the gap between national initiatives and EOSC. The project is largely composed and coordinated by IBERGRID. LIP participates in the project management and contributes in the areas of software quality, services integration and digital repositories. In this context the group is also participating in the EOSC architecture working group.

In the INDIGO-DC context, LIP continued to participate in the DEEP-HybridDataCloud project which aims to develop technologies for large scale deep learning using cloud, HPC and hardware accelerators. LIP coordinates the software management and pilot infrastructure activities, and participates in several R&D activities related to accelerated computing and containers. The udocker tool development, maintenance and integration were supported by DEEP-HybridDataCloud and EOSC-hub projects.

Lines of work and objectives for next year

LIP computing services

Improve the LIP-Lisbon computing infrastructure by adding capacity to the shared storage system that supports the home directories. Improving the LIP internal virtualization platform adding capacity and further flexibility. The development of the LIP internal authentication, authorization and user registration systems will continue aiming at providing a portal for user management and service registration.

WLCG and Tier-2

Improve the network connectivity for the WLCG Tier-2 and evaluate options for caching only storage at the Tier-2 level in order to decrease the need for larger storage. Evaluate options to increase the capacity and also exploit opportunistic computing resources through INCD and the advanced computing network. Continue working with the LIP management and the LHC groups to seek a solution to address the existing Tier-2 and Tier-3 capacity shortcomings.

INCD

Continue to execute the INCD P2020 infrastructures project. For 2020 these activities include the expansion of the INCD-Minho node with additional storage and compute capacity to reinforce the current INCD computing cluster in Minho, and enable the deployment of a second cloud computing service federated with the existing Openstack service in Lisbon. The computing cluster service and cloud services in Minho will be integrated in IBERGRID and EGI. Minor capacity improvements in the INCD-Lisbon node are also foreseen. Continue improving the infrastructure monitoring and accounting systems. Deploy a data repositories pilot service in partnership with FCT-FCCN. Continue the collaboration with other national thematic infrastructures. Participate in the advanced computing network being established by FCT.

EGI, IBERGRID and EOSC

Continue to liaise 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 in this international infrastructure. The IBERGRID collaboration will continue providing an umbrella for Iberian participation in EGI.

Continue the participation in the EOSC-hub, that joins EGI, EUDAT and INDIGO-DataCloud. LIP coordinates the software Configuration, Change, Release and Deployment management activities in EOSC-hub for all cloud, grid and data oriented services. LIP will continue supporting the udocker tool as part of the common services provided by EOSC-hub . Jointly with LNEC, will continue improving and operating the OPENCoastS thematic service in EOSC-hub providing on-demand forecasts for the European Atlantic coast.

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 will participate in the areas of quality assurance and services integration in the European Open Science Cloud.

Participation in R&D&I projects

Continue participating in the DEEP-hybrid-DataCloud project, where LIP is contributing in the areas of high performance computing and Linux containers applied to machine learning. The LIP activities also include the coordination of the software management and pilot infrastructure. Start the BigHPC project in partnership with TACC, INESC-TEC and WAVECOM aims at the development of an innovative management framework for Big Data and parallel computing workloads.

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. These activities will continue until the end of the INCD P2020 project that will be extended to 2021. The objective until then is to position INCD so that it can apply for further funding from the national research infrastructures roadmap.

The group plans to enlarge its participation in High Performance Computing (HPC) related activities. Two approaches are envisage, participation of the future national competence center in EuroHPC, and providing services to the research community through INCD in the context of the FCT advanced computing network.

Participation in international infrastructures is expected to continue. These include WLCG, EGI and IBERGRID. The activities will include improvement of the infrastructures via R&D projects, operations, and collaboration with researchers from other domains. The current participation in the European Open Science Cloud opens new opportunities for collaboration that will be further explored. The activities will be extended with a pilot on data repositories in cooperation with FCT-FCCN.

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.

Participation in R&d&I projects will continue at national and international level within the context of the participation in the IBERGRID, EGI, INDIGO-DC, EOSC and other initiatives.

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 via INCD. Participation in the FCT infrastructures roadmap.
- Users from multiple disciplines and organizations.

Weaknesses

- Hardware ageing and lack of processing and storage capacity.
- Cash flow and administrative issues are compromising the execution of the INCD funding.

Opportunities

- Maintain and improve the IT infrastructure services in partnership with INCD.
- Consolidate and optimize scientific computing resources distributed across several organizations.
- Enable future policies for scientific computing and open access. Potential for industrial and e-government applications. Possibility of engagement with other communities.
- Expand activities to further encompass high performance computing and data repositories.

Threats

- Lack of resources to fulfill the WLCG requirements.
- Lack of coherent policies for scientific computing and digital infrastructures.
- Lack of funding for operational costs.
- Shift in national strategy towards supercomputing.

GRID

Publications

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

- *"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, Environmental Modelling & Software, 2019, 104585, ISSN 1364-8152

2 International Conference Proceedings

- *"OPENCoastS: on-Demand Forecast Tool for Management"*, Marta Rodrigues, João Rogeiro, Samuel Bernardo, Anabela Oliveira, André B. Fortunato, Joana Teixeira, Pedro Lopes, Alberto Azevedo, Jorge Gomes, Mário David, João Pina, Proccedings of the Fourteenth International MEDCOAST Congress on Coastal and Marine Sciences, Engineering Management and Conservation MEDCOAST 2019, 22-26 October 2019, Marmaris, turkey, ISBN: 978-605-69747-0-0
- *"Benchmarking Deep Learning Infrastructures by Means of TensorFlow and Containers"*, Adrian Grupp, Valentin Kozlov, Isabel Campos, Mario David, Jorge Gomes, Álvaro López García, In: Weiland M., Juckeland G., Alam S., Jagode H. (eds) High Performance Computing. ISC High Performance 2019. Lecture Notes in Computer Science, vol 11887. Springer, Cham

1 National Conference Proceedings

- *"Geração Automática de Sistemas de Previsão Costeira: a plataforma OPENCoastS"*, André B. Fortunato, João Rogeiro, Joana Teixeira, Anabela Oliveira, Alberto Azevedo, Xavier Bertin, Laura Lavaud, Mário David, João Pina, Jorge Gomes, Sonia Castanedo, Fernando Mendez, Pedro Lopes, Marta Rodrigues, IX Congresso sobre Planeamento e Gestão de das Zonas Costeiras, Lisboa 2019

12 Collaboration notes with internal referee

- *"DEEP D3.3 - Status of Software releases"*, Cristina Duma (INFN), Pablo Orviz (CSIC), Mario David (LIP), German Molto (UPV), Marcin Plociennik (PSNC), DEEP-Hybrid-DataCloud project deliverable
- *"INCD Mi6.1 Lisbon node Deployement and Readiness"*, Jorge Gomes, INCD P2020 project deliverable
- *"EOSC-hub D4.2 Operational Infrastructure Roadmap"*, J.Pina (LIP), A.Paolini, M.Viljoen, V.Spinoso, P.Weber, J.Reetz, G.Morelli, I.Bierenbaum, D.Vicente, D.Kelsey, D. Scardaci, N.Liampotis, EOSC-hub project deliverable
- *"EOSC-hub D7.2 First report on Thematic Service architecture and software integration"*, C.Cacciari, D.Uytvanck, W.Elbers, D.Spiga, T.Weigel, S.Fiore, P.Mazzetti, M.Santoro, A.Oliveira, A.Azevedo, M.David (LIP), A.Bonvin, A.Rosato, B.Garcia, M.Verlato, C.Briese, M.Manunta, M.Gil, S.Mantovani, P.Baumann, G.Milcinski, F.Pacini, D.Davidovic, EOSC-hub project deliverable
- *"INCD Mi8.2 Revised Documentation Materials"*, Catarina Ortigão, João Pina, Jorge Gomes, INCD P2020 project deliverable
- *"INCD Mi1.3 All Specialized Centres Established"*, Catarina Ortigão, INCD P2020 project deliverable
- *"EOSC-hub D6.2 First report on the maintenance and integration of common services"*, H.Widmann, C.Cacciari, M.D'Antonio, J.Reetz, A.Ceccanti, C.Martens, E.Fernandez, C.Condurache, J.Gomes (LIP), A.Tsaregorodtsev, G.Molto, M.Antonacci, B.Kryza, B.Wilk, P.Orviz, T.Zok, L.Dutka, M.Karlsson, H.Piggelen, T.Weigel, S.Bendoukha, EOSC-hub project deliverable
- *"INCD Mi6.2 Centre and Northern Nodes Deployment Status"*, Jorge Gomes, INCD P2020 project deliverable
- *"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
- *"INCD Mi3.3 Relations with Users 2nd Periodic Report of the activities"*, Catarina Ortigão, INCD P2020 project deliverable
- *"INCD Mi5.2 Enhanced Implementation of Cloud Services"*, Catarina Ortigão, Mario David, Jorge Gomes, INCD P2020 project deliverable
- *"EOSC-synergy D1.4 Quality Plan"*, Jorge Gomes (LIP), Elisa Cauhé (EGI), Miguel Ángel (IFCA), EOSC-synergy project deliverable

1 Articles in Outreach Journals

- *"Computação Avançada em Portugal"*, Jorge Gomes, INCoDe.2030 Newsletter #04

Presentations

11 Oral presentations in international conferences

- Mário David: *"EOSC, FAIR & Software"*, 2019-04-24, Workshop on Sustainable Software Sustainability 2019 (WOSSS19), The Hague, Netherlands
- Mário David: *"udocker support for accelerators"*, 2019-05-07, EGI Conference 2019, WCW Congress Centre Amsterdam, Netherlands
- João Pina: *"Implementing the open science cycle with EGI Jupyter, datahub, github, zenodo and binder"*, 2019-09-17, Open Science Fair 2019, Alfândega Congress Center, Porto, Portugal
- Jorge Gomes: *"IBERGRID infrastructure status (IBERGRID 2019)"*, 2019-09-23, IBERGRID 2019, Santiago de Compostela, Spain
- Samuel Bernardo: *"Rootless containers with udocker (IBERGRID 2019)"*, 2019-09-23, IBERGRID 2019, Santiago de Compostela, Spain
- Diana Maria Naranjo Delgado: *"Comparison of Container-based Virtualization Tools for HPC Platforms"*, 2019-09-23, IBERGRID 2019, Santiago de Compostela, Spain
- André Vieira: *"Experience with the GÉANT Cloud IaaS Framework Agreement"*, 2019-09-24, IBERGRID 2019, Santiago de Compostela, Spain
- João Pina: *"EOSC-hub TCOM SQA area: status and future"*, 2019-09-25, IBERGRID 2019, Santiago de Compostela, Spain
- Jorge Gomes: *"Performing computations using Docker containers in interactive and batch systems, in Grids, Cloud and HPC systems"*, 2019-09-26, IBERGRID 2019, Santiago de Compostela, Spain
- Mário David: *"Using OpenStack Cloud infrastructures"*, 2019-09-26, IBERGRID 2019, Santiago de Compostela, Spain
- Jorge Gomes: *"The power of digital e-infrastructures: EOSC Hub"*, 2019-11-27, Europeana 2019 Workshop on EOSC's Evolutionary Scenarios: Perspectives for Digital Cultural Heritage, National Library of Portugal, Lisbon

1 Poster presentations in international conferences

- Mário David: *"Rootless Containers with Udocker (ISC 2019)"*, 2019-06-18, ISC High Performance 2019, Frankfurt, Germany

2 Oral presentations in international meetings

- Jorge Gomes: *"udocker"*, 2019-03-28, CompBioMed Containerisation Meeting, SurfSara, Amsterdam
- Mário David: *"udocker tool"*, 2019-09-19, CNRS/IN2P3 Atelier ComputeOps no 3 : conteneurs pour le calcul intensif, Paris, France

3 Presentations in national conferences

- Jorge Gomes: *"Géant Agreement Experience"*, 2019-05-06, Jornadas FCCN 2019, University of Azores
- Jorge Gomes: *"INCD - Computação para a Ciência e para o Ensino"*, 2019-05-07, Jornadas FCCN 2019, University of Azores
- Jorge Gomes: *"Lessons for effective use of Advanced Computing"*, 2019-07-03, Ciência 2019, Centro de Congressos de Lisboa

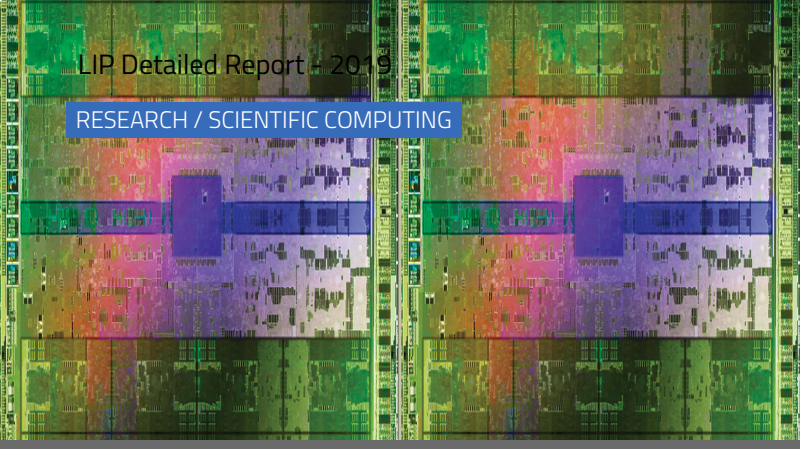
3 Seminars

- Jorge Gomes: *"Data protection and best practices for end-users in IT (GDPR)"*, 2019-01-31, LIP seminar, Lisbon
- Nuno Ribeiro Dias: *"Best practices for end-users in IT"*, 2019-02-28, LIP seminar, Lisbon
- Mário David: *"udocker tool"*, 2019-06-16, Colloquium KIT, KIT Karlsruhe, Germany

Organized Events

1 International Conferences or Workshops

- ***"IBERGRID2019"***, Santiago de Compostela, Spain, 2019-09-23 to 2019-09-26



ADVANCED COMPUTING

Advanced Computing - Minho

Principal Investigator:
António Pina (75)[+]

3 ***Master Student(s):***
Bruno Ribeiro (100)[+], Tiago Duarte (100)[+], Tiago Gonçalves (21)[+]

3 ***External collaborator(s):***
António Esteves, José Ru no, Vítor Oliveira

Total FTE:
3

Completed theses:
1 Master

Executive summary

Members of advanced computing group have previous work in Grid, HPC, computing models, high performance communication libraries and distributed data structures. Research also encompass R&D on the combination of traditional multicore CPUs with acceleration devices. The group, part of the LIP-Minho since the beginning of 2014, has been directing its activity to the fields of Computer Science and Engineering more closely related to the principal areas of interests of LIP research. In particular, it is noteworthy the support for the development and optimization of code applications related to high energy physics and the search of 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

Lines of work and team organization

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 infra-structures;
- machine learning and training;
- advanced training: Linux, Concurrent C++.

Achievements and responsibilities during the past year

The work developed closely followed the objectives set for the year 2019. In this context, the emphasis was placed on the following activities:

- To continue the process of enriching the pedagogical projects of 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 the work of the LIP;
- Launching of new computer training activity for young researchers;
- Involvement in the ATLAS collaboration.

The activities developed by the group resulted in:

- On the context of project “BigDataHEP: Understanding Big Data in High Energy Physics”:
  - conclusion of one MSc thesis "Resource-Oriented Computing Platform (PlaCoR)";
  - on-going MSc thesis related to the “Distributed Training of Deep Neural Networks”,
  - start of a new MSc thesis related to paralell/distributed multithread programming: "Study, evaluation and application of the HPX platform".
- Communication (with review) and presentation
  - Ribeiro, A. Pina, *PlaCoR Plataforma para a Computação orientada ao Recurso*, 11º Simpósio de Informática- Inforum 2019, Guimarães, Sept 2019, Portugal*;*
- Fourth edition of the course, “The Basics of the LINUX Command Line” in UMinho;
- 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 2020, 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 mantain the local computing infra-structure Cluster infrastructure and the CPU/GPU machine learning system.

We also expected to be able to attract new students for R&D in the group main scientific areas, in particular:

i) performance analyse of HEP data analysis applications
ii) evaluation of alternatives to developing hybrid shared/distributed memory applications
iii) development of a platform intended to allow the efficient processing of data integration to “Understanding Big Data in High Energy Physics”. Expecting to get financial support to PhD thesis through the CERN PhD Grants Program

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 (2019/2010) Call for SR&TD Project Grants in all scientific domains.

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

Strenghts

- A group with solid foundation in the parallel and distributed computing scientific domains;
- International R&D collaboration experience as a result of the active participation in several EU 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

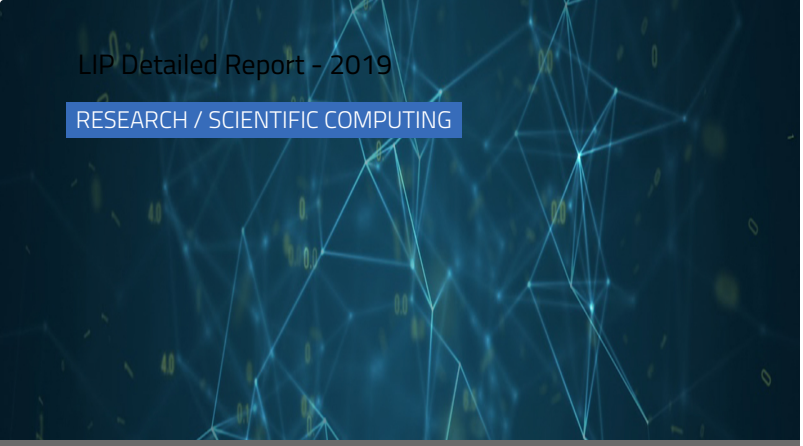
- Local HPC infrastructure has no guarantee of continuity of service by lack of financial support for equipment maintenance/upgrade and system administration;
- In Portugal, there are no unemployed graduates in Computer Engineering. In this context, it is very difficult to attract to scientific work young people, without the availability of funds, to support new scholarships for MSc or PhD.

Theses

1 Master

- Bruno Ribeiro: *"PlaCor: Plataforma para a Computação Orientada ao Recurso"*, 2017-10-02 / 2019-06-14, (finished)

RESEARCH / SCIENTIFIC COMPUTING



SPAC [x]

Social Physics and Complexity

Principal Investigator:
Joana Sá (100)

3 ***Researcher(s):***
Lília Perfeito (100), Simone Lackner (100), Sofia Pinto (100)

1 ***Technician(s):***
Paulo Almeida (100)

1 ***PhD Student(s):***
Sara Mesquita (100)

Total FTE:
6

(x) Starting in 2020

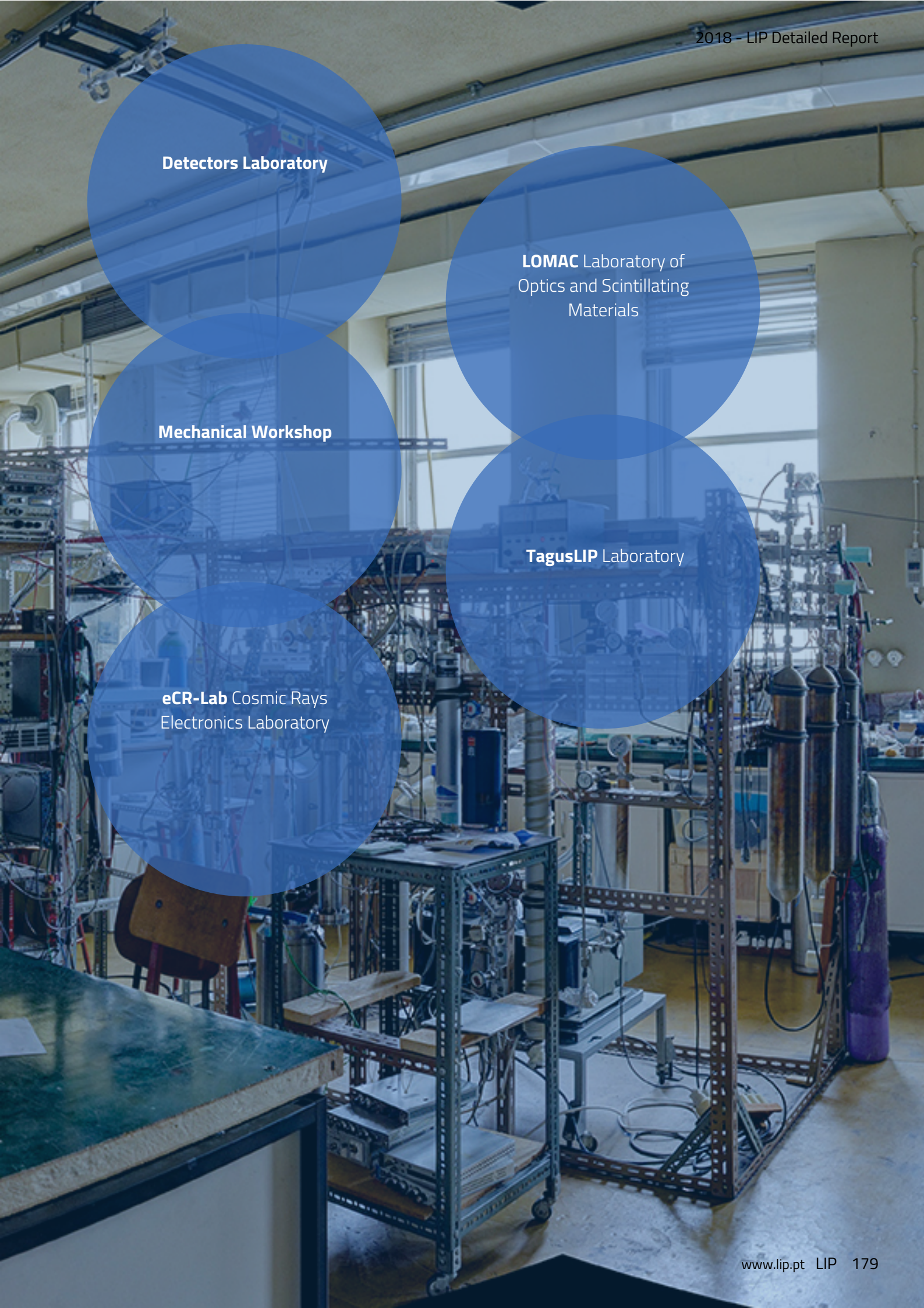
Executive summary

The Social Physics and Complexity has very recently joined LIP. SPAC uses large scale computational tools to study societal challenges, especially in disease forecasting, human behavior and public policy. This multidisciplinary research group takes advantage of the so-called “Big-Data Revolution” and works together to understand how individual behaviour impacts on society. We also focus on the risks that these technologies might entail and we help establish the guidelines for ethical uses of data science and artificial intelligence.
The European Research Council has awarded a Starting Grant to the group PI to conduct the research project “Fake News and Real People – Using Big Data to Understand Human Behaviour (FARE)”.

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. Right now, the so-called Digital Revolution is offering radically new ways to study complex behaviours and this is being recognized by physics and computer science departments in many top universities worldwide. Complexity Science (CS) studies complex systems and tries to identify general principles. Complex systems consist of a large number of interacting heterogeneous components (parts, agents, humans etc.), resulting in highly non-linear and unpredictable behaviour, with emergence properties. CS theory typically builds on statistical physics and dynamical systems, but also on information theory and, increasingly, network science.

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. In fact, many of the methods developed by statistical and particle physics are now being applied to societies and there is a growing perception that physics will be fundamental to study sociology and even psychology. Leading scientists are calling this new science “Social Physics” and arguing that, in some ways, complexity science will study the physics of human interactions.

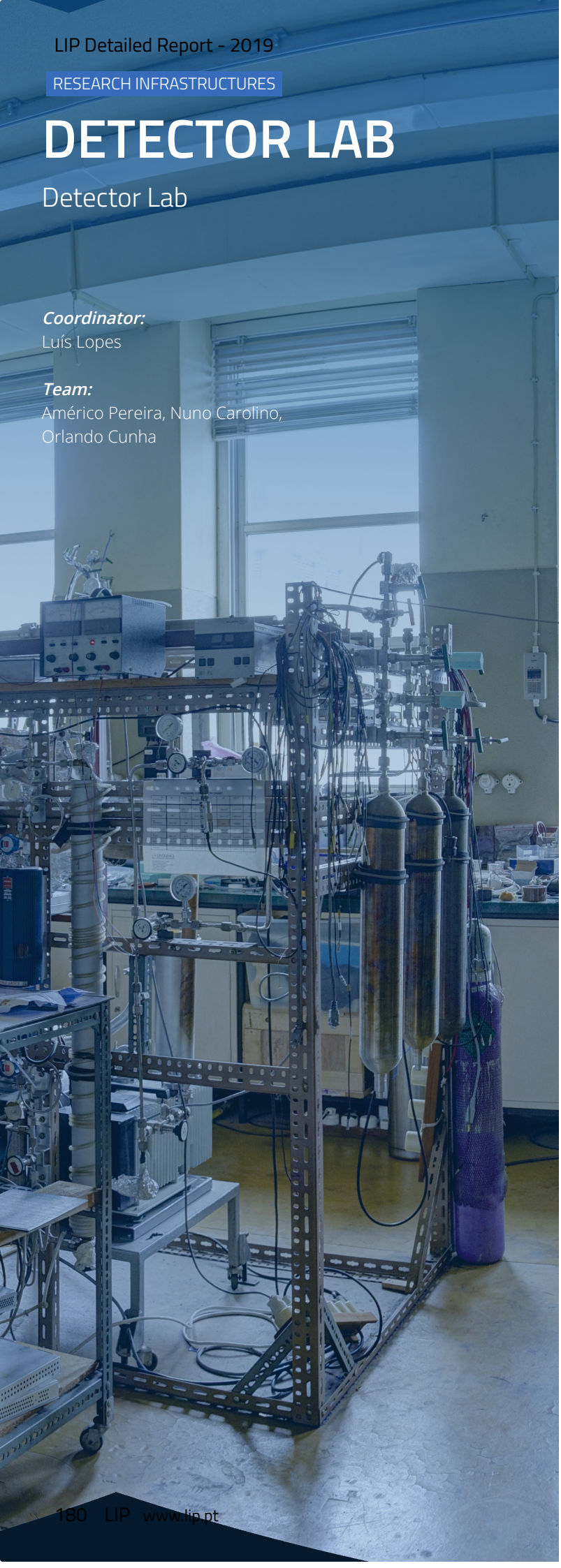
RESEARCH Infrastructures


Detectors Laboratory
LOMAC Laboratory of Optics and Scintillating Materials
Mechanical Workshop
TagusLIP Laboratory
eCR-Lab Cosmic Rays Electronics Laboratory

RESEARCH INFRASTRUCTURES

DETECTOR LAB

Detector Lab



Coordinator:
Luís Lopes

Team:
Américo Pereira, Nuno Carolino, Orlando Cunha

Brief description of the facilities

LIP's Detectors Laboratory (DL) is currently split into two different facilities:

F1 is where the research groups develop their work and all electronics projects are developed. Situated in the fourth floor of the Physics Department, it is equipped with most of the instrumentation and tools needed in a detector 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 main research, development and production of large area radiation detectors takes place. Situated in the ground floor of the Physics Department, this area has been set up during the last years. At present, only about 80% of the foreseen area is available for our activities. In 2019, some improvements were made. The installation should be finalized in 2020. 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 tests. Most of the mandatory instruments and tools are available in adequate quantity and quality.

Detector Lab

Activities and achievements during the past year

The main activities were related to 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 MARTA, MuTom, SHiP, HADES-FD, STRATOS, AnimalPET and BrainPET. Our contribution is multidisciplinary, since we fulfill almost all the necessary steps: from the project design to the installation and maintenance of the detectors; developing tools and/or instruments to control/monitor the detector performance; adapting the detector to the individual requirements of each application, following more or less the same procedure done in the industry. In 2019 we reached the 101 units. This activity consumes around 30% of our total personpower. For a more detailed description of our contribution to these projects, it should be consider that we develop from the beginning the detector sensitive volume, the gas control and monitoring system, the monitoring of all the environmental properties that could affect the detector performance. All other parts used in these detectors were developed with the contribution of the researchers related to these projects. Probably the most important activity is our capability to assist all the groups in their R&D activities. In 2019, this consumed about another 35% of our human resources. We contributed with technical work and added value in the following projects: Animal-PET, SNO+, HADES, SINE2020, Cloud Chamber, GSPC.LIP, OrthoCT. Besides detector work, this included the layout, loading and testing of PCBs home made electronic boards.

More technical, management-related tasks were fulfilled, concerning namely maintenance and upgrade tasks in both the DL and in LIP's Mechanical Workshop (MW). Organization and purchase of materials and instruments for LIP-Coimbra and for the Physics Department are task in which the DL also has a relevant contribution.

Another set of activities is related to direct contracts for the provision of services and products by the DL to external clients. In total this corresponded to 10% of our manpower and returned a considerable income (more than 25% of the annual staff cost, more than 25 k€). The LIP Spark Chamber ir now a direct responsibility of the DL. As first action we made some improvements that reduce the production costs in more than 30%. We also produced three Spark Chambers and repaired two. The first prototypes of a sealed RPC were built and successively improved since 2018 and at the moment we reached the final detector design and production of the first 2 units.

Plan for next year

Continue to push for the improvement of the new facilities (F2) is of major importance in order to achieve the established production targets. The bureaucracy is however huge! He hope we can install the ISO 6 Clean Chamber and open the possibility to develop and construct different kind of radiation detectors and instruments.

We also start a major process to identify all the modules, instruments and tools available in our facilities. The main goal is to keep only the useful ones and create a system that easily allows all collaborators to know what is available for their R&D.

We expect the production of large area RPCs to be lower this year. We will: finish the HADES-FD and STRATOS. 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 for sure become available.

Concerning the support to other groups, the DL is expected to contribute in the constructing, assembly and test of the following projects and/or setups: the Brain-PET; RPCs for neutrons within SINE2020; Cloud Chamber; GSPC.LIP; HADES; SHiP.

There will, in addition, be R&D contributions for several projects, namely HADES-MDC and muTom RPCs. The sealed RPC is a major development, even more in the context of global warming issues.

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 demands of the LIP research groups, which is our main task. In this way we will also be able meet the requirements of some 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.

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 be "important" and take profit from our expertise.

More precise plans for the medium and long term are difficult (or impossible) to outline, once we are mostly a support infrastructure that needs to follow the needs and options of the research groups. For this reason, our prospects are, in the first "3 to 5" orders, the prospects of the research groups.

SWOT analysis

Strengths

We have a multidisciplinary team that allows us to give a satisfactory answer to most of the requests. For this it is also important to note that we are well equipped. The ease with which we move to the places where LIP has its hardware, thus allowing a continuous monitoring from the R&D phase to the installation, operation and maintenance of most of the systems developed and built. This close monitoring allows a constant learning and improvement of our knowledge and abilities.

Weaknesses

Our current facilities are far from being indicated for the development of our activities. Space is limited and the time needed to change something in this situation is huge, sometimes unacceptable. Our production capacity and consequently our efficiency are greatly diminished for this reason. This was improved in 2019 and we strongly expect to reach an acceptable situation until the end of 2020.

Another important cause of inefficiency comes from not requesting the work in advance. Approximately 20 to 25% (getting better when comparing with past years) of jobs with more than 5 days of execution are requested less than a month in advance, or the information needed to execute them is only available within the same time frames. In this way it is impossible to make an efficient programming. Another issue is the non consulting of our expertise (getting worse when comparing with past years) in many issues in which we in fact are experts, frequently leading to waste of time due to bad preparation of the work. We systematically alert all the collaborators to this issue, but in some cases we were not successful.

Opportunities

The establishment of the ruggedness and performance of some of our detectors has been opening novel markets. After projects such as muTT and Antarctica we are 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 more 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. Last year we got more than 25 k€ in direct contract of DL products and services for external groups, including research centers, universities and the industry.

Threats

The uncertainty in some of our funding sources in medium and long term. The successive failure of the delivery times from our suppliers.

RESEARCH INFRASTRUCTURES

WORKSHOP

Mechanical Workshop

Coordinator:
Alberto Blanco

Team:
Carlos Silva, Douglas Lima, Jorge Moreira, Nuno Filipe Silva Dias, Rui Alves

Brief description of the facilities

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 (four technicians and one engineer) 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 very clear that, in the absence of MW, it would not have been possible for LIP to fulfill with the same high level of quality all the work in detector R&D, or all the responsibilities in international collaborations. (CP-LEAR, DELPHI, HERA-B, ATLAS, HADES, MARTA, SNO+). Equally evident are the benefits to the national R&D community, at local and national level.

Workshop

Activities and achievements during the past year

2019 has been a year with many projects (around 54) and 100% of the time occupied. Here a list of the main projects together with some relevant information:

- Final construction, assembling and test of a second unit of the Umbilical Retrieval Mechanism (URM) (device for the deployment of calibration sources) for the SNO+ experiment. Finished early 2019.
- Construction of **HADES-FD** prototype for in-beam measurements.
- Construction of a chamber for testing new structures of gas amplification for **Gaseous Detector R&D.**
- Construction of mechanics for **MUTOM** tomography project.
- Mechanics for the first head of **HRezBrainPET.**
- Construction of three spark chambers for **Outreach**.
- Construction of mechanics for two units of **MARTA** type detectors.
- Relocation of the infrastructures, maintenance and management.
- Other projects. Support and construction of mechanical parts for the following groups and entities: Detector Laboratory, LATTES, SHiP, RPC R&D (Antarctica), ATLAS, Portuguese Institute of Oncology (IPO), Chemistry Department (DQ), and other small works.

As mentioned in the 2018 report, our current lathe operator will leave LIP in 2020. So we started looking for a person to replace him already in 2018. As hiring an experienced lathe operator proved to be an impossible task (due to lack of market candidates), we decided to hire a person without experience, but with potential. To train him ourselves.

Finally, the complete relocation of the MW in its new location (activity pursued during the last three years since it was relegated to a second plane to give priority to running projects) was completed by the end of 2019.

The large area (3x2 m²) CNC machine especially devoted to the construction of large area detectors was delivered at LIP first week of 2020.

Plan for next year

A few large projects are already allocated for 2019, the most significant ones are listed here:

- Design and construction of the complete mechanics for HiRezBrainPET.
- 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.

Medium-term (3-5 years) prospects

Beside the continuous work for the LIP research projects and external groups/companies, in the next years we plan to consolidate/improve the MW:

- We need to consolidate the new lathe operator after the leaving of the current one.
- We want to use the same software tools that we use 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 CAD software which will improve performance. This is currently 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.
- The relocation of the MW to the new space will improve the working conditions, thus improving the efficiency.
- The hiring of a new staff member (lathe operator, who will leave in 2020) opened the opportunity to explore new capabilities of the CNC machines.
- Opportunity to extend our services to other research groups / companies.
- New capabilities with a new large area CNC machine.

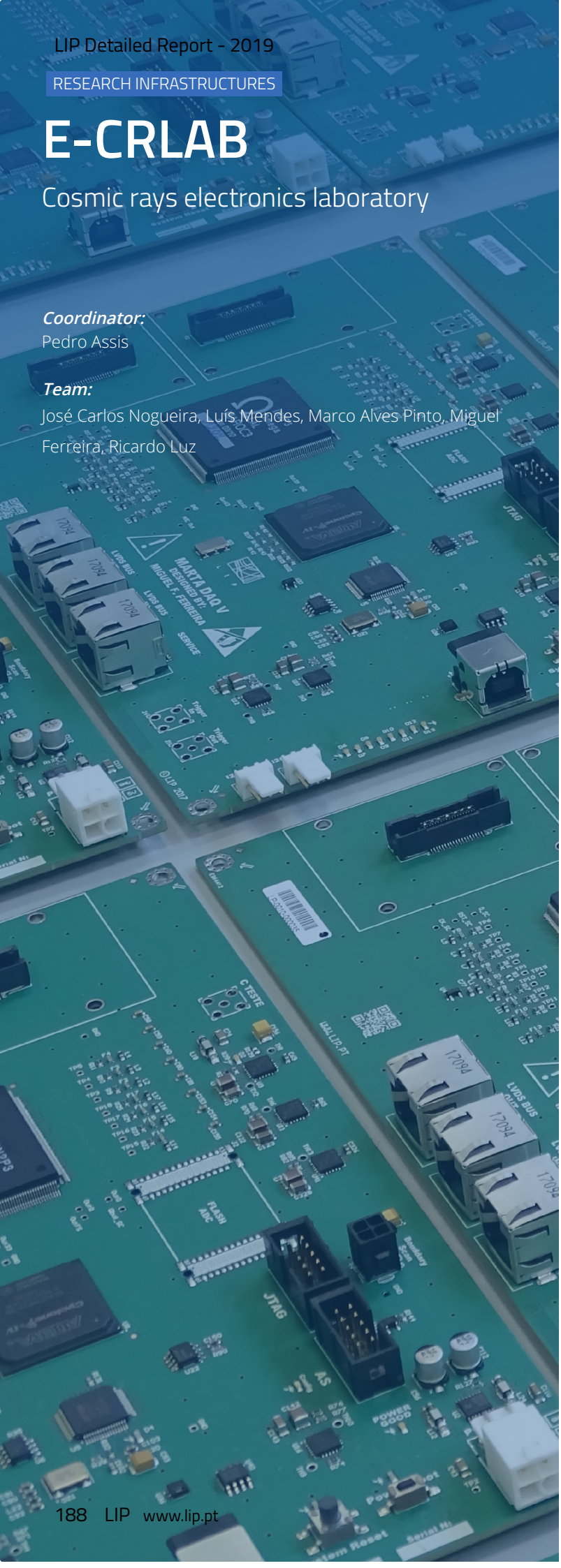
Weakness & Threats

- Difficulty in working simultaneously in many projects.
- Obsolescence of some of the equipment.

RESEARCH INFRASTRUCTURES

E-CRLAB

Cosmic rays electronics laboratory



Coordinator:
Pedro Assis

Team:
José Carlos Nogueira, Luís Mendes, Marco Alves Pinto, Miguel Ferreira, Ricardo Luz

Brief description of the facilities

The e-CRLab (electronics for Cosmic Ray Laboratory) is dedicated mainly to the development of electronics for Cosmic Ray experiments. The main 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 the capability to do rework in PCB boards. A small set of mechanical tools allows for the production of simple detector prototypes mainly for a proof of concept. The laboratory facilities are located at LIP-Lisboa and are composed by an office room, one 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 its activities. The capability to produce PCBs is installed at LIP premises in a separate room. The laboratory counts with two researchers, two PhD students and three electronics technicians.

e-CRLab

Activities and achievements in the past year

The e-CRLab has given a great contribution to the MARTA project. The production and test of the front-end system has been done. The system was completely designed at the laboratory and production outsourced. The e-CRLab also had the responsibility to design and produce support systems for MARTA slow control. The Central Unit of the system has been developed based on a development board from Intel based of a hybrid system coupling a microprocessor to an FPGA (SOC-FPGA). The monitoring and control system of MARTA has been developed and tested and is in its commissioning phase.

The acquired know-how was employed in several other activities that led to the development of experimental setups. Firstly, in the context of the Pierre Auger Collaboration, muon hodoscopes were deployed using the MARTA DAQ and the slow control which double as the MARTA-test stand.

Instrumentation of other hodoscopes for the Lousal Muon detector have been implemented and a setup for SWGO/Lattes has also been implemented.

The infrastructure has also developed work in the radiation damage studies. With the Space Radiation group, it was possible to develop a small setup for the characterization of different components and their response to radiation. The understanding of the change in measurable parameters with radiation opens a line of using COTS (Commercial Off The Shelf) components to measure the radiation eld. This work, developed in the framework of a Master Thesis, will be continued producing instruments to be tested under irradiation.

The know-how in the development of electronics has been disseminated by giving support to the development of electronics for the upgrade of ATLAS.

It was also given support to teaching and outreach activities by developing and maintaining experimental setups.

Plan for next year

The next year will be critical for the commissioning of the developed systems. Namely, we expect to be able to solve the problems identified during the MARTA commissioning and to have the first data in the first semester. Solutions have already been idealized and will be deployed in the test stand and in the eld. We will also proceed with the deployment of around 5 more stations. The hodoscopes in Auger are expected to nalize their commissioning and start regular tests of other detectors.

The setup at the Lousal mine is expected to be upgraded with 4 plane hodoscope and lessons learned in Auger will be integrated in the setup. Studies on the performance of the RPCs are expected to be realized in close collaboration with the RPC group and the Detector Laboratory infrastructure.

We expect that the developments on the MARTA Front-End will be adopted for other projects. The OMEGA group is upgrading the ASIC and as such we will be forced to update the design of the board to meet the new packaging of the ASIC. We will also introduce intelligence to the board (microprocessor) which will increase the versatility of the board and also allow to develop know-how on these solutions.

We will also seek to increase the contribution to the development of electronics for the ATLAS upgrade, incorporating the know-how of the e-CRLab in the designs.

The studies of radiation damage are of key importance and will be pursued in close connection with the Space Radiation Effects group.

We are also starting to investigate the possibility to use developed, or similar, solutions in proton-therapy activities. We foresee the use of the MAROC-board, with a slight adaptation of the interface, as the readout of a micro-dosimeter and we are studying the possibility to participate in the instrumentation of other detectors being developed at LIP.

We plan to continue the support to teaching activities with the development and operation of Cosmic-Ray related experimental setups. We also foresee to give support to the Laboratory of Radiation and Atomic Physics by introducing CR setups and by upgrading the electronics, where possible.

Medium-term (3-5 years) prospects

The infrastructure plans to secure its acquired competence in the 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 Lattes will be of key importance. We will pursue a closer connection with the RPC group, developing and implementing DAQ systems for other projects they are involved in.

Furthermore we will also pursue external collaborations. We have already established contacts with groups interested in using similar systems to the developed ones and also are contacting the OMEGA group to establish a stronger partnership.

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 financing for the development of detectors. The level of financing is incompatible with the full development of detectors. Even in these condition, we must make an effort to keep publishing the work developed.

Opportunities

The MARTA Engineering array gives the opportunity to lead the development of a medium size project from end-to-end. 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 e-CRLab and Master thesis developed in e-CRLab can allow to increase personpower in the laboratory and allow to pursue different projects. The know-how acquired in the laboratory can also boost the participation in novel projects. The investment plan resulting from the FCT evaluation plan will allow to increase the capability to test-and-measure.

Threats

Financing is always a key issue when developing hardware that needs to spend in service acquisition and materials. Lack of personpower could also be an issue in the mid-term.

RESEARCH INFRASTRUCTURES

LOMaC

Laboratory of optics and scintillating materials

Coordinator:
Agostinho Gomes

Team:
Amélia Maio, João Gentil, Luís Gurriana, Luís Seabra, Ricardo Gonçalo, Rute Pedro

Brief description of the facilities

LOMaC was created for the test and preparation of WLS bres for the ATLAS TileCal project in the 1990s, with human resources and expertise from CFNUL, LIP, FCUL, and UNL. The entire WLS bres 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 bres, 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 bres; Optical bre aluminization facility (by magnetron sputtering); Fibrometer – automated device for the characterization of sets of up to 32 optical bres; Mono- brometer – automated device for the characterization of individual optical bres; Tilemeter – automated device for the characterization of scintillators; PMT test device – automated test bench for the characterization of PMTs; Equipment to measure absolute light yield;

LOMaC selected and/or prepared the following optical fibres, in chronological order: R&D of scintillating and WLS fibres and scintillators for ATLAS; WLS fibres for the DELPHI STIC luminosity monitor; WLS fibres for the ATLAS TileCal; Scintillating fibres for the ATLAS ALFA luminosity monitor; R&D for future calorimetry (DREAM project); Clear fibres for the SNO+ calibration system; WLS fibres for W104/Icarus muon tagger; WLS fibres for the ATLAS Tilecal gap/crack scintillators and MBTS upgrade;

LOMaC also studied the light output and uniformity of scintillators for TileCal, having designed the optical masks to improve their uniformity, and tested a set of PMTs also for TileCal. It also gave crucial support to the development of the plastic pro les that house the WLS bres in the TileCal calorimeter.

With the end of CFNUL, LOMaC was forced to abandon the building where it was hosted, and was set up at FCUL in 2016. Since LIP moved to the 3Is unit of the University of Lisbon, we already reassembled part of the equipment at LIP.

LOMaC

Activities and achievements in the past year

After the preparation of WLS optical fibres for the Tilecal upgrade done by the end of 2018, the contribution for the ATLAS upgrade continued in 2019 with the preparation of sets of WLS fibres for the Minimum Bias Trigger Scintillators (MBTS). Since the MBTS is located much closer to the beam pipe, its scintillators suffer severe damage due to radiation, and in this shutdown the most exposed ones were replaced by radiation harder green scintillators developed at IHEP Protvino. So the sets of fibres included the orange O3 fibres produced by Kuraray in addition to the usual green Y11 fibres.

For Tilecal, we keep sets of WLS fibres from the Tilecal production and they were studied again for the purpose of ageing studies. The measurements of attenuation lengths are compatible with the initial ones, so within the experimental limits of the order of 5% we do not see any significative loss of transparency.

Also for the Tilecal upgrade, the PMT test bench was setup again at the LIP lab and it was set partially operational. This effort was a contribution for the setup and refurbishment of the several PMT testbenches of CERN, Pisa and Bratislava that will be used in the upgrade phase II to test new and retest part of the old PMTs of Tilecal.

The fibrometer remains at FCUL lab and was used in all the fibres preparations and tests. It required additional maintenance includding the replacement of a broken power supply.

The old lathe of 3Is was installed at its new location. To make it operational it is still needed to prepare all the auxiliary systems to hold the bundles of fibres, an adaptation of the system used in the milling machine used formerly for the cutting/polishing of the bundles.

For tests of microdosimetry, scintillating fibres with diameters of 0.5 and 0.25 mm of type SCSF78, offered by Kuraray, were prepared. Associated with this work, a new testbench was prepared to test ribbons of these very small scintillating fibres.

A new light sensor (SiPM) system was setup. Scintillators used in the tests for the detectors for the Future Circular Collider (FCC) were tested both with the old PMTs and the SiPM for comparison. The new system shows smaller fluctuations but the signal to noise ratio still needs to be improved.

Preliminary work was done by our collaborators of CEFITEC for the deposition of very thin layers of transparent film in polystyrene scintillators and in PMMA to improve the efficiency of light collection in those plastic materials.

LOMAC along the year gave a strong contribution for education and outreach. In the LIP Summer internships there were 6 students at LOMAC including one from University of Liverpool, one from Brazil and one from Madrid in the framework of Erasmus. We contributed also for the Ciencia Viva OCJF “Criar Futuro” with 4 students at the lab and for several FCUL activities for young students.

Plan for next year

For 2020, the transfer of the aluminization equipments for the new place at the 3Is basement lab is starting. Depending on the needs for tests and operational conditions at FCUL and 3Is, the transfer of the fibrometer will be evaluated later in the year.

Due to the ageing of the fibrometer and tilemeter equipments it is necessary to upgrade them. The design of a new flexible system for the characterization of scintillators and fibres based on RPCs will be done, using when possible technologies developed and available at LIP.

We intend also to continue the upgrade of the PMT testbench, to allow its usage in the tests of the new Tilecal High Voltage system.

For the next year the collaboration with the LIP Dosimetry Group is foreseen, for the characterization of scintillating optical fibres for applications in microdosimetry. A new setup to hold the fibres will be prepared.

Work with lab tests for detectors for FCC (scintillators, fibres and SiPM) and R3B (scintillating fibres tracker) will continue. In the same way ageing studies of Tilecal optics focusing on scintillators and fibres are planned.

Medium-term (3-5 years) prospects

In the medium term LOMaC contributions will focus in 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 effort to better estimate the degradation of the main scintillators and WLS fibres of TileCal.

The second area is to contribute for the studies for scintillator based detectors for the Future Circular Collider. Studies using scintillators, WLS fibers and several photodetectors will be done.

The third area corresponds to applications in microdosimetry, where 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

Recent discussions and the preparation of the FCC-hh Conceptual Design Report have demonstrated that the TileCal design is still one of the best for a hadronic calorimeter. This opens the opportunity to participate in new detectors in HEP or related fields.

Threats

Lack of sustained operations in future is possible.

LOMaC

Publications

1 Collaboration notes

(with internal referee)

- *"Calorimeters for the FCC-hh",* C. Neubuser, R. Goncalo, J. Gentil, CERN-FCC-PHYS-2019-0003

RESEARCH INFRASTRUCTURES

TAGUSLIP LABORATORY

TagusLIP laboratory

Coordinator:
João Varela

Team:
Luis Ferramacho, Miguel Silveira, Rui Pereira da Silva, Tahereh Niknejad

Brief description of the facilities

The TagusLIP Laboratory is a LIP research infrastructure installed in 2004 at the Lisbon Science and Technology Park (Taguspark). The campus is home to a University (IST), several research centres as well as a large spectrum of startup's and PME's. TagusLIP was conceived as a generic infrastructure for the development of radiation detectors in the areas of PET imaging and experimental particle physics. TagusLIP includes detector and electronics laboratories, electronics workshop, a hot laboratory for work with radioactive sources, offices space, and meeting rooms.

The TagusLIP laboratory is equipped with the necessary instrumentation for R&D on radiation detectors and associated electronics and data acquisition, including electronics lab equipment, computing and networking systems. The laboratory offers software tools for developing analog and digital electronic integrated circuits, for firmware development, and for the design of printed circuit boards. 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. 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 reading-out the data of 80'000 scintillating crystals. 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 6 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 thousands channels. PETsys Electronics has customers in four continents, America, Europe, Asia and Australia, and in 2018 and 2019 had sales exceeding 1 M€/year. Most of the sales correspond to small test systems with the TOFPET2 ASIC. Nevertheless, several PET scanner prototypes with PETsys Electronics technology are being built by different companies, some of which have already decided to adopt PETsys Electronics technology.

Activities and achievements in the past year

In 2019 the main users of the TagusLIP Laboratory were the LIP-CMS research group and the start-up company PETsys Electronics. The following activities have been performed:

LIP CMS group

1. System simulations of the TOFHIR2 ASIC performance under the MTD/BTL operation conditions, in the frame of the Phase II Upgrade of the CMS experiment for HL-LHC. The development of the new ASIC TOFHIR2 is pursued in collaboration with PETsys Electronics.
2. Test of the TOFHIR1 ASIC performance using a dedicated test system, SiPMs and laser light.
3. Development and test of the first prototype of the BTL Front-End Board (FE) integrating 6 TOFHIR1 ASICs.

PETsys Electronics

1. Characterization of the performance of the ASIC TOFPET2 for special applications as requested by costumers.
2. Development, fabrication and testing of an updated version of the ASIC TOFPET2 (version 2d) suitable for pulses with negative polarity (as generated by PMTs or MCPs).
3. Organization of the production, testing and supply of PETsys Electronics products.
4. Microelectronics design of the TOFHIR2 ASIC following the specifications of the LIP-CMS group. PETsys Electronics is responsible for the microelectronics ASIC design and the LIP-CMS group develops the integration of the chip in detector modules. The MPW submission of the first version of TOFHIR2 is scheduled to February 2020.
5. 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 PETsysElectronics TOFPET2 ASIC. The final detector will consist of 28,800 channels.

The results obtained were presented at several international conferences, including IEEE/NSS/MIC 2019 in Manchester.

Plan for next year

The LIP-CMS group and the company PETsys Electronics will be the main users of the TagusLIP Laboratory in 2020.

LIP-CMS group

The R&D activities in the CMS Barrel Timing Layer (BTL) planed by the LIP-CMS group are described elsewhere in this report and summarised here:

1. Pursue the tests of the first prototype of the BTL Front-End board (BE) with the TOFHIR1 ASICs, and integration in the BTL Readout Unit. Tests with sensor modules are foreseen at TagusLIP and CERN.
2. Test of the TOFHIR2 ASIC designed by PETsys Electronics using the Test Board developed by LIP. Integration with detector modules based on LYSO crystals and SiPMs and characterization with laser light and radioactive sources.

PETsys Electronics

The activities of PETsys Electronics in 2020 include:

1. Tests of components and systems supplied by PETsys Electronics.
2. Pursue the development of the dedicated frontend electronics for the PANDA experiment.
3. Design of the second version of the ASIC TOFHIR2 (TOFHIR2 v2). Submission is planned in Q1 2021.
4. Participation in the activities of the Consortium TOF-PET for Proton Therapy, which had a funding request for the development of proton therapy on-line monitoring recently approved. The responsibility of PETsysElectronics in this project is to develop and supply the readout and data acquisition systems.

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.

TagusLIP laboratory

Publications

1 Articles in international journals

(with indirect contribution from the team)

- *"On light sharing TOF-PET modules with depth of interaction and 157 ps FWHM coincidence time resolution"*, M. Pizzichemi, A. Polesel, G. Stringhini, S. Gundacker, P. Lecoq, S. Tavernier, M. Paganoni, E. Auffray, Phys. Med. Biol. 64 (2019) 155008

COMPETENCE CENTRES


Monitoring and Control
Competence Center
Simulation and Big Data
Competence Center

COMPETENCE CENTRES

CCMC

Competence Centre in Monitoring and Control

Coordinator:
Francisco Neves

Team:
Filipe Veloso, Helmut Wolters, João Carlos Silva

(x) Starting in 2020

Overview

The Competence Centre in Monitoring and Control (CCMC) is intended to:

1. Gather the accumulated expertise in sensors, electronics and software used in monitoring and control by several experiments in which LIP groups participate and have direct responsibilities;
2. Facilitate the sharing of know-how and solutions in electronics and software design among LIP persons/groups with the potential bene t of:
    - Reduce development and delivery times;
    - Better debugging and quality control;
3. Establish partnerships/contracts with third parties (e.g. other laboratories, industry) where our scientific deliverables can be re-used.
    - Avoid the time and costs associated to the development of new products.

CCMC

Last year activities

The activities of the CCMC developed in the framework of other LIP members/infrastructures were:

1. Implemented the temperature monitor and control system used during the test campaign (at Forschungszentrum Jülich) of the future TOF detector for the forward region of the HADES spectrometer. These tests aimed at characterizing the efficiency and timing accuracy of the detector as a function of its working temperature.
2. Continue the development of a complete software framework intended to be used as the basis solution when deploying our products. The software is being design to be easily extended and interface with virtually any hardware used in monitoring and control while at the same time supplying a user friendly front-end for displaying and manipulation of data.

Concerning external entities, the activities were:

1. Field testing and final delivery of non-invasive devices (version 1) for the monitoring of the temperature and heart rate of birds during nesting in their natural habitat for the group ECOTOP from the MARE-UC institute.
2. Development and implementation of the software tool to extract and process information (e.g. filter ambient noise, detect the presence of birds in the nest) from the temperature and heart rate monitors.
3. Also for the group ECOTOP from the MARE-UC institute, the CCMC started the development and implement an improved version (version 2) of the temperature and heart rate monitors for nesting birds. The improvements aim at increasing the device autonomy and the accuracy of the temperature measurement.

Prospects for next year

For the next year, the CCMC plans to:

1. Continue to mature the software framework currently being developed and benchmark it within the activities of one or more LIP groups. A thorough testing of the software in real conditions is crucial to ensure its robustness before its deployment to third parties;
2. Field testing of version 2 of the devices for monitoring the temperature and heart rate of birds before the final product delivery (schedule for mid March);
3. For the group ECOTOP from the MARE-UC institute, the CCMC will develop and build a device to control and monitor ambient parameters of nests installed in the natural habitat of birds. A set of these devices will be installed scatter over a large forest area aiming at studying potential effects of the temperature increase associated with climate changes in the nesting of birds.
4. Install an environmental monitoring system for the server room at LIP-Coimbra;
5. Participation at the event "Techdays: Building our future" in Aveiro, in the context of the work developed with the group ECOTOP from the MARE-UC institute. This participation presents also an opportunity to expose the CCMC to other opportunities and potential clients.
6. Organize a workshop on “Monitoring and Control for scientific and industrial applications” (last quarter of the year). The event aims not only at disseminating LIP-CCMC's capabilities but also at getting a better insight on the needs of potential clients and/or partners.

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 in 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, constructions 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 LIP product 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 at competitive prices.

Threats

1. The ability to meet deadlines and ensure the personpower required for the assistance to services/products contracted with third party entities and it potential impact in the LIP image.

COMPETENCE CENTRES

SIMULATION & BIG DATA

Competence Centre on Simulation and Big Data

Coordinator(s):
Nuno Castro and Bernardo Tomé

Team:
Alexandre Lindote, Ana Peixoto, António Pina, Bruno Ribeiro, Celso Franco, Daniel Galaviz, Diogo Gonçalves, Filipa Peres, Filipe Veloso, Giles Strong, Guilherme Milhano, Henrique Carvalho, João Pedro Gonçalves, Liliana Apolinário, Lorenzo Cazon, Luisa Arruda, Marco Alves Pinto, Miguel Fiolhais, Miguel Romão, Patrícia Gonçalves, Paulo Brás, Paulo Crespo, Pedro Lagarelhos, Raúl Sarmento, Ricardo Barrué, Ruben Conceição, Rui Curado Silva, Rute Pedro,Tiago Duarte, Tiago Gonçalves, Tiago Vale, Vladimir Solovov

Undergraduate Students:
Céu Neiva [x], José Fernandes [x]

(x) Starting in 2020

Overview

The purpose of the Competence Center on Simulation and Big Data is the fostering of an effective collaboration between the different LIP groups working on these areas and to boost the capability to exploit the existing expertise both internally and externally, towards the academy and industry. The different LIP groups have a vast range of competences in data analysis and simulation tools, including physics models, Monte Carlo generators, detector simulation tools, big-data handling techniques and data mining. The ability to fully benefit from such competences requires achieving critical mass, a coordinated training program, the exploitation of synergies between groups and a clear identification of the key areas in which we can contribute in a competitive way.

The competence center started its activities almost 3 years ago, but had a significant boost in 2019 with dedicated human resources, allowed by the obtained funding, and some projects external to LIP. For the immediate future the challenge is the consolidation of the center and the expansion of the projects and connections with academia and society.

Simulation & Big Data

Last year activities

The Simulation branch of the competence center developed the following activities:

- Teaching of advanced detector simulation techniques as part of the curricula of specific undergraduate courses and doctoral programs.
- Participation in the activities of the Geant4 collaboration. Support and maintenance to one Advanced Example, for which LIP is responsible, was kept, namely in view of the last Geant4 release.
- Support to the needs of LIP research groups was provided; in particular, a close collaboration with muon tomography simulation activities was maintained.
- Participation of the LIP members responsible for the Ants2 simulation tool in the activities of the competence center was strengthened.
- Several developments, namely in the context of the specific activities of the LIP groups were also undertaken. In particular,
    - The iAstro group started developing a mass model simulation of the instruments for the AMEGO NASA mission proposal, using the Geant4-based simulation tool MEGAlib. This tool was also used in simulations of the Experimental setup of Larix beamline (Univ. Ferrara, Italy) gamma-ray polarimetric experiment.
    - Major updates to Ants2 were implemented, namely the possibility to automatically delegate particles transport to Geant4. Ants2 capabilities to simulate optical photons has significantly increased its application range and is being cross-validated against Geant4. New analysis and GUI features were also introduced.

The Big-Data branch of the competence center developed the following activities:

- Study and development of machine learning techniques for the detection of rare events at colliders, resulting in 4 publications, 4 completed MSc. thesis and some presentations in workshops.
- Organization of the 2nd School and Symposium “Data Science in (Astro)Particle Physics and Cosmology: the Bridge to Industry”, Braga, March 2019.
- Established a partnership with Nielsen, aiming to analyse data on their audictors.
- Application of machine learning to analytical chemistry data to identify contaminants in printed circuit boards produced in industrial lines in the context of the iSci-Bosch-ECUM project.
- 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).

Prospects for next year

The Simulation branch of the competence center will continue its contribution to the teaching of advanced detector-simulation methods at graduation and doctoral programs. The participation in the Geant4 collaboration will be continued as well as the support to the needs of the LIP groups. Within the activities of the i-Astro group a mass model simulation for the STRATOSPOLCA ESA Balloon experiment will be developed using MEGAlib. Several updates to Ants2 will be introduced, targeting namely on the tracing speed, through the use of GPU processing, and the possibility of using Ants2 as a general-purpose front-end for Geant4. Ants2 specific features should be explored in particular in the context of its potential attractiveness for use in didactics applications. An introductory course on Geant4 will be organized in February at the University of Minho (Braga). Editions of the course in Coimbra and Lisbon are also planned during 2020.

On the Big Data side, the ongoing funded projects allowed, in 2019, to hire dedicated human resources through contracts and grants, which boosted the activities of the center. Currently two MSc. thesis and two PhD thesis are in progress. Even if the production of papers and thesis is not the core goal of the competence center, such production demonstrates the know-how of the team and, in some cases, such papers and thesis reflect direct applications of the team skils and techniques to multidisciplinary problems, as targeted by the competence center.

The Data Science School and Symposium event has become a series of events rather than a sporadic one, with the 3rd one foreseen to happen in Coimbra, in March 2020. Several companies and academic partners have participated in the symposium so far and a significant number of students, mostly at PhD level, attended the school. This results in a community being built around these events and thus we should make sure to benefit from that by establishing new joint projects and consolidating the existing ones.

Medium-term (3-5 years) prospects

The medium term strategy of the Simulation and Big Data Competence Center aligns, naturally, with LIP's strategy. Therefore, we should be able to contribute in a transversal way to all the strategic areas with needs in terms of simulation and data handling. The Competence Center should have its activities consolidated, following the plan defined at its creation, three 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.

SWOT analysis

Strengths

- Long standing expertise in simulation and big data at LIP.
- Expertise in modern data handling and machine learning techniques used in HEP and beyond.
- Integration in international collaborations (HEP experiments, Geant4 collaboration).
- Ongoing projects in machine learning provides funding to the activities, in particular for dedicated human resources.
- First partnership with a private company (Nielsen) was successful.
- The data science symposium and school provides a rich community to exchange ideas, know-how and projects.

Weaknesses

- Despite having more researchers and students working in this field, we are still below the critical mass in some areas.
- The competence center has not yet fully exploited the possibilities provided by the network created with the data science symposium and school.

Opportunities

Huge interest and demand for expertise in simulation, big data and data mining.

Interest in modern techniques by many LIP members.

Large interest in the areas of the Competence Center by different funding agencies.

The Data Science Symposium allowed us to get 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 possibility of synergies with new researchers in data science joining LIP.

Threats

The data science community is very large and extremely competitive, going well beyond the HEP community. In order to be effective, we should focus our efforts in areas where we can be competitive.

Difficulty in providing external services in a more sustained way.

Sources of funding

PI	Code	Amount	Dates	Description
Nuno Castro	PTDC/FIS-PAR/29147/2017	239.988 €	2018-07-01 / 2021-06-30	BigDataHEP: Understanding Big Data in High Energy Physics: finding a needle in many haystacks

Total: 239.988 €

Simulation & Big Data

Publications

4 Articles in international journals

(with direct contribution from the team)

- *"Reconstruction of top quark pair dilepton decays in electron-positron collisions"*, Helenka Casler, Matthew Manganel, Miguel C. N. Fiolhais, Andrea Ferroglia, António Onofre, Phys. Rev. D 99, 054011 (2019)
- *"A Roadmap for HEP Software and Computing R&D for the 2020s"*, HEP Software Foundation, Johannes Albrecht et al., Comput. Softw. Big Sci. 3 (2019) no.1, 7
- *"Search for large missing transverse momentum in association with one top-quark in proton-proton collisions at $sqrt{s}=13$ TeV with the ATLAS detector"*, ATLAS collaboration, JHEP 05 (2019) 41
- *"From the Bottom to the Top - Reconstruction of tt Events with Deep Learning"*, Johannes Erdmann, Tim Kallage, Kevin Kröninger, Olaf Nackenhorst, JINST 14 (2019) P11015

Presentations

3 Oral presentations in international conferences

- Rute Pedro: *"Measurements of Higgs boson production using decays to two b-quarks with the ATLAS detector"*, 2019-07-11, EPS-HEP Conference 2019, Ghent, Belgium
- Nuno Castro: *"Top-quark FCNC in production and decay processes"*, 2019-09-23, Top 2019 - International Workshop on Top Quark Physics, Beijing, China
- Tiago Vale: *"Data Science in High Energy Physics"*, 2019-09-25, Ibergrid - 10th Iberian Grid Conference, Santiago de Compostela, Spain

3 Presentations in national conferences

- Nuno Castro: *"Big Data and Machine Learning in High Energy Physics"*, 2019-07-08, Encontro Ciência 2019, Lisboa
- Nuno Castro: *"The Portuguese participation in the upgrade of the Large Hadron Collider at CERN"*, 2019-07-09, Encontro Ciência 2019, Lisboa
- António Pina: *"PlaCoR Plataforma para a Computação orientada ao Recurso"*, 2019-09-05, INForum - Simpósio de Informática, Guimarães

1 Seminars

- Diogo Gonçalves: ***"Machine Learning in Chemistry: is a machine capable of outsmart a trained chemist?",*** 2019-04-10, Ciclo de Palestras do Centro de Química da Universidade do Minho, Braga

2 Outreach Seminars

- Nuno Castro: ***"Do infinitamente pequeno ao infinitamente pequeno",*** 2019-05-16, , Escola Secundária do Marco de Canaveses
- Nuno Castro: ***"Física de Partículas: a ponte entre o infinitamente grande e o infinitamente pequeno",*** 2019-10-16, IX Ciclo de Conferências Científicas, Vila Nova de Famalicão

2 Oral presentations in international meetings

- Nuno Castro: *"Big data and machine learning at LIP"*, 2019-04-26, 2nd joint workshop IGFAE-LIP, Santiago de Compostela, Spain
- Tiago Vale: *"Rare event detection in High Energy Physics"*, 2019-09-20, UT Austin Portugal Program 2019 Annual Conference, Braga

1 Oral presentations in advanced training events

- Nuno Castro: "Probing the Standard Model and Beyond at the LHC", 2019-02-11, 4th Lisbon mini-school on Particle and Astroparticle Physics, Costa da Caparica, Portugal

Theses

3 PhD

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

6 Master

- Diogo Gonçalves: *"Machine Learning in Analytical Chemistry: Applying Innovative Data Analysis Methods Using Chromatographic Techniques"*, 2017-09-01 / 2019-10-25, (finished)
- Bruno Ribeiro: ***"PlaCor: Plataforma para a Computação Orientada ao Recurso",*** 2017-10-02 / 2019-06-14, (finished)
- Filipa Peres: *"New observables and techniques for the study of jets in hadron collisions",* 2018-09-15 / 2019-12-12, (finished)
- João Pedro Gonçalves: "Topic modelling for jets", 2018-11-01 / 2019-11-29, (finished)
- Maura Teixeira: ***"Search for monotop events at the LHC using machine learning"***, 2018-10-01 , (ongoing)
- Tiago Duarte: *"Treino de redes neuronais profundas de forma distribuída",* 2018-10-01 , (ongoing)

Organized Events

1 International Conferences or Workshops

- *"Data Science in (Astro)Particle Physics and Cosmology: the Bridge to Industry"*, [Conf-WS-Int] 2019-03-25 / 2019-03-29, Braga

1 Collaboration Meetings

- *"1st general meeting of the BigDataHEP project"*, [Coll-Mtg] ID: 327, 2019-01-11/ 2019-01-11, Coimbra

Science and Society

Knowledge transfer, industry and spin-offs

Radiation, health and environment

Advanced training

LIP-ECO Education, communication and outreach

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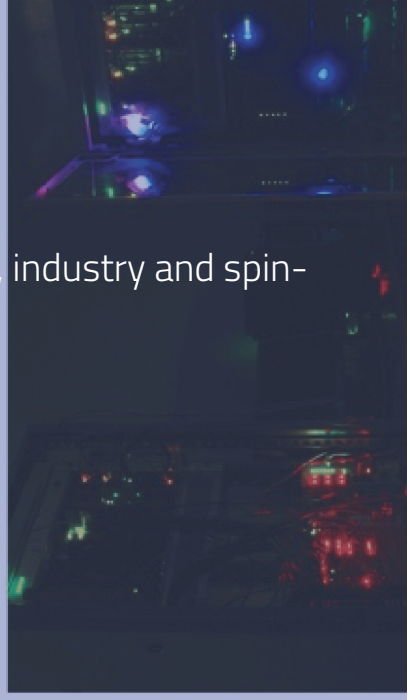
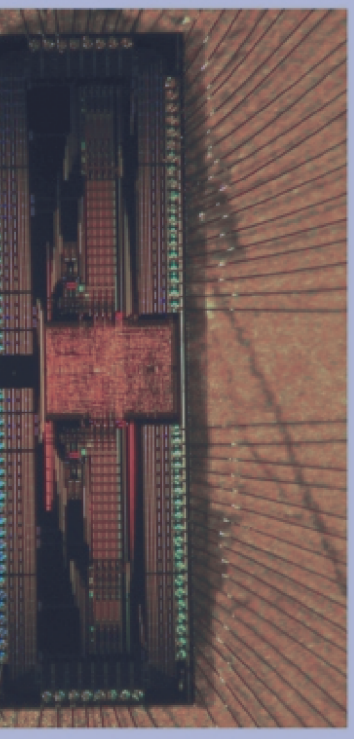
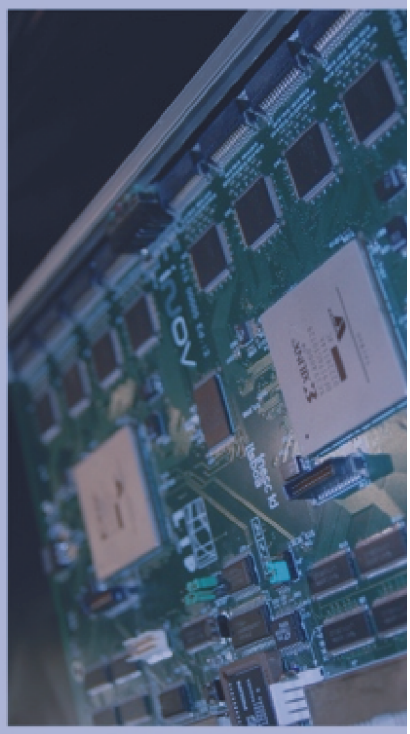
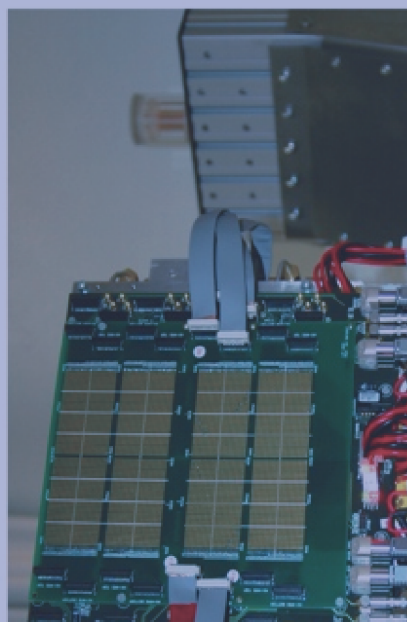
Knowledge Transfer, industry and spin-offs









Overview

Particle physics technologies have a wide range of applications, and the potential to respond to societal changes. Knowledge transfer opportunities exist across the full spectrum of LIP's activities, from the LHC upgrade to medical and space application of radiation detection technologies and to scientific computing. The reinforcement of the collaboration with a wider community, both academic and non-academic, national and international, in an interdisciplinary context is a mandatory challenge, and a great opportunity for the laboratory. Besides the accumulated know-how and experience of its research groups, LIP's scientific support infrastructures and competence centres will play a crucial role. LIP is instrumental in creating opportunities for Portuguese industry at CERN and in other international laboratories and research facilities. The recently renewed protocol between Portugal and CERN recognizes LIP as CERN's reference laboratory in Portugal. While CERN remains our main partner, LIP is now a partner of ESA and belongs to international collaborations at GSI,SNOLAB, Auger and SURF. In 2019 a new industrial liaisons officer (ILO) was appointed by FCT with the mandated to support and actively promote national industry and R&D institutions to CERN, ESO and ESRF left FCT. Finally filling this gap created in mid 2018 is of the highest importance to ensure a positive industrial return to Portugal. In 2019 has been confirmed the installation in Portugal of a centre for proton therapy. LIP is a founding 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. This is certainly and excellent opportunity for knowledge transfer and for establishing both academic and industrial partnerships. Below, 2019 activities are reviewed and priorities for 2020 are established.

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2019 Activities

Portuguese official and industrial visits to CERN
The Minister of Science, Technology and Higher Education, the Secretary of State for Internationalization, and the President of the Foundation for Science and Technology (FCT) visited CERN on September 2019. The visit was accompanied by the Portuguese Delegate at the CERN Council and President of LIP, and by the Portuguese Ambassador to the United Nations in Geneva. The delegation included representatives from several other Portuguese institutions, namely universities, innovation, investment and internationalization agencies, and companies. We highlight the presence of the LIP Directorate and several LIP researchers, and of representatives of all our stakeholders. The visit aimed to reinforce the Portuguese presence at CERN in its scientific, technological and industrial aspects, in particular concerning the full exploitation of the opportunities created by the LHC accelerator upgrade program by Portuguese companies.

ProtonTherapy in Portugal During 2019 it was confirmed that Portugal will have a centre for proton therapy including both treatment and research facilities. The ProtoTera Association was created in December 2019 and its founding members are the Portuguese Institute of Oncology Hospital Group, Instituto Superior Técnico, the University of Coimbra, and LIP. ProtoTera will promote the development of a national research and education network on advanced therapies and associated technologies, leveraging the research, training and healthcare infrastructures associated with the treatment of patients with cancer using new technologies. Areas and technologies covered include, among others, high-energy particle beam therapies, theranostics for the enhancement of precision and personalized medicine, and advanced medical imaging. The association will stimulate the development of funding programs for research and advanced training and qualification in these areas, promote fundraising and networking among the various associates and other entities, and ensure international scientific, technical and clinical cooperation, in particular with the International Atomic Energy Agency and international reference centers, namely CERN, GSI, Heidelberg University Hospital, MD Anderson Cancer, Trento Proton Therapy Center, etc. Within this interdisciplinary network, several groups at LIP have the potential to give major contributions. Funding has already been secured for two projects: a collaboration between the LIP OR imaging and Dosimetry groups and a consortium led by PETsys in the framework of the Portugal-Austin Program. Two further exploratory projects involving the LIP Dosimetry and SpaceRad groups, as well as the LOMaC facility, have been prepared for the UTAustin Portugal Program 2019 Call for Exploratory Proposals.

PETsys Electronics spin-off
The development of TOFPET1 ASICs for PET Time-of-Flight applications was at the origin of the start-up company PETsys Electronics in 2013. A technology transfer contract between LIP and PETsys Electronics 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. Benefiting from the infrastructure available at TagusLIP, PETsys Electronics was able 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) within increased performance, and developed also complete SiPM readout and data acquisition solutions for detector systems with tens thousand channels. Most of its sales correspond today to small test systems with the TOFPET2 ASIC . The participation in the activities of the Consortium TOF-PET for Proton Therapy had a funding request for the development of proton therapy on-line monitoring recently approved.

LHC Upgrade
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. In 2019 the activities of the LIP CMS and ATLAS groups towards the Phase 2 Upgrade for operation at HL-LHC continued in full swing, following the approval in 2018 by FCT and the Minister of Science and Technology of the participation of LIP in the Phase 2 Upgrade of both experiments. The CMS group participates in the construction of a new Timing Detector and in the upgrade of the barrel and end-cap Calorimeters. The group is responsible for the design and construction of the readout system of the Barrel Timing Layer (BTL), including a high-performance TOF ASIC for time measurement. In collaboration with industry, LIP provides a high-performance ADC ASIC for the ECAL front-end electronics resistant to radiation. The CMS upgrade includes also the complete replacement of the end-cap 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 HGCAL front-end system experiments. In the ATLAS group, a strong effort will be dedicated to the detector upgrades for the TileCal and trigger systems. Concerning the TileCal, the main effort will be the full production of the new high voltage distribution system for the Phase II Upgrade of TileCal, that involves the Portuguese industry, and the continuous upgrades of the detector control system. Systematic studies of the ageing of the optical components (scintillators and fibres) in LOMaC 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.

RPCs and HiRezBrainPET

The project "Neurofunctional cerebral imaging by high resolution positron emission tomography (PET)" was approved. The project is led by ICNAS-Produção Unipessoal, a biomedical company fully owned by the University of Coimbra, and has as partners LIP and the Polytechnic Institute of Coimbra. The total investment will be slightly over 500 thousand euros. This project is part of the INTERFACE Program of SI I&DT PT2020, which establishes and promotes links between higher education institutions and companies. In this project, we intend to develop an innovative PET scanner with sub-millimeter spatial resolution using RPC-based detection technology. The equipment to be developed has the potential to change the paradigm in the diagnosis and investigation of, for example, diseases of the central nervous system. The collaboration between LIP and ICNAS for R&D in the RPC-PET technology has been going on for several years. On the other hand, the STRATOS project for the construction of two cosmic ray telescopes for the monitoring of the stratosphere temperature in cooperation with the HYDRONAV S.A company will be finished in the short-term. The continuation of the collaboration with HYDRONAV with the aim to designing and building a macro scanner for cargo containers in ports will be pursued in the medium-term.

Space exploration

LIP's space activities are based upon collaboration with industry, contracts with the European Space Agency and participation in consortia for H2020 calls (LIP is member of the EUROPLANET and in currently in consortia with EFACEC and EVOLEO). 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 small increase in the budget for the Portuguese participation in the ESA Exploration programme. In this context, a group of experts is being created to advise the PT-Space agency on this subject, of which Patrícia Gonçalves is a member.

Computing

The LIP computing groups have extensive knowledge and experience in scientific computing, excellent international relations and integration in scientific e-infrastructures, with users from multiple disciplines and organizations, participate in the FCT infrastructures, and in the enabling of future policies for scientific computing and open access. LIP co-leads the National Infrastructure for Distributed Computing, serving the Portuguese scientific community at large, and has growing expertise in data science and big data. This creates the potential for industrial and e-government applications and the possibility of engagement with other communities in addressing a number of societal challenges.

LIP's scientific infrastructures and competence centres

They provide support to our activities but also services to external entities. In 2019, direct contract for the provision of services and products by LIP's Detectors Lab to external clients returned an income corresponding to more than 25% of the annual staff cost. The purpose of the recently created LIP Competence Centers is to exploit the existing expertise both internally and externally, towards the university and industry. The Simulation and Big Data Competence Center is part of several European Consortia, in particular a COST action. It also organizes the Data Science School and Symposium, which become a regular event series. This results in a community being built, helping to launch new joint projects and consolidating the existing ones. A partnership has been established with Nielsen, aiming to analyse data on their auditors. Application of machine learning to analytical chemistry data to identify contaminants in printed circuit boards produced in industrial lines in the context of the iSci-Bosch-ECUM project. The Monitoring and Control Competence Center is providing services do other research institutes at the University of Coimbra.

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 for 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. Avery positive feedback from the supervisors is testimony of the importance and success of the programme.

HEPTech network
LIP is a member of HEPTech, a unique high-energy physics technology transfer network (TTN) that aims to become "the innovation access point for accelerator and detector driven research infrastructures". The network brings together leading European high energy physics research institutions and tries to bridge the gap between researchers and industry by organizing a set of activities: academia industry matching events; workshops on technology transfer and commercialization of research, etc. LIP, as an HEPTech node member, follows the various activities and maintains updated awareness about knowledge and technology transfer. In 2018, José Carlos Silva has been appointed as the new LIP representative in HEPTech. A new HEPTech site is now in operation and HEPTech is co-sponsoring/co-hosting the European Cryogenics Days 2020,scheduled for May 24-26 in the Netherlands. In June 16-17 LIP will host the HEPTech board meeting.

Prospects for 2020

LIP will continue to stimulate knowledge transfer by reinforcing its links to academia industry, for different applications, all across its areas of activities. The priorities are the following:

- **LHC ugrade:** It constitutes a unique opportunity for collaboration between LIP and industry.The work in the upgrade will be intense in the next couple of years.

- **Proton-therapy in Portugal:** It is an opportunity making the perfect match with LIP's medical instrumentation research activities and creating opportunities for collaboration with the academia and industry, both at national and international levels.

- **RPC R&D:** Both the project "HiRezBrainPET: neurofunctional cerebral imaging by high resolution positron emission tomography (PET)", and the production of sealed RPCs, able to work with no gas flux, are developments with the potential to change the paradigm in their areas.

- **Scientific computing and big data:** Scientific computing is certainly one of the areas placing LIP at the forefront of innovation. To exploit knowledge transfer opportunities and to address societal changes in this area is certainly a priority.

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 ***Master Student(s):***
Soraia Elísio (100)

2 ***External/Additional scientific collaborator(s):***
Patrick Sousa, Pedro Gabriel Almeida

Total FTE:
5.6

Overview

The group focused his work in the study of radon gas in the air and water in certain regions of Angola and the study of radon exhalation. A study to measure the radon mass exhalation rate from common granite building materials used in the East and Northeast part of Portugal was carried out. Twelve cubic shaped samples were measured. Nine of them without any coating and three coated with different materials (varnish, hydrorepellent and liquid silicone). The radon measurements were performed with two different techniques: one using passive detectors and other using an active detector. For the passive method CR-39 solid state nuclear track detectors were used. The active method used the RAD7 DURRIDGE detector.

Radiation, health and environment

Last year activities

A new version of the radon monitor based on a low-cost photodiode with Arduino acquisition was built and tested. Two units are ready to be deployed in Angola. The measurement of radon mass exhalation rate from common granite building materials used in the East and Northeast part of Portugal was made. Twelve cubic shaped samples were measured. Nine of them without any coating and three coated with different materials (varnish, hydrorepellent and liquid silicone). The radon measurements were performed with two different techniques: one using passive detectors and other using an active detector. For the passive method CR-39 solid state nuclear track detectors were used. The active method used the RAD7 DURRIDGE detector. Radon mass exhalation rates obtained from both methods present relatively low values in the 10 to 40 mBq kg^{-1} h^{-1} range for the analysed samples. Concerning the coated samples, the measured values are on average four times lower than the ones without coating. Overall the measured values for both methods present a good agreement. The radon laboratory (LabExpoRad) located at Beira Interior University began last year the accreditation process which is expected to be completed by 2020. LabExpoRad will be the second laboratory in the country with accreditation to perform air and water radon analysis.

Prospects for next year

1. Collaboration with the Computing Engineering Department and the Town Hall of Fundão to develop and build an IoT ecosystem in smart home environments that integrate and use a number of wireless sensors, such as humidity, temperature, CO, CO2and radon gas, to detect, predict and evacuate the radon gas from buildings.

2. Study of the effect of aerosols containing radon on the development of aromatic plants: The objective is to analyze the effects and potential consequences on the biological development of aromatic plants exposed to different concentrations of radon. The development/growth will take place in an isolated chamber connected to a radon generator. The relative growth rate will be determined by studying the absorption of essential inorganic nutrients and the possible bio-remediation effect of heavy metals associated with radon.

3. Assessment of indoor air quality - NORM: This work intends to carry out radon exhalation tests of granites from different sources, common in indoor environments, intended for homes or workplaces, using controlled and isolated atmospheres in order to be able to establish a catalog of granitic materials, of low radon exhalation, with the objective of contributing to the improvement of indoor air quality.

4. In the scope of the training program "Train the trainees - Train future trainers in radiation protection and nuclear technology"the LabExpoRad will held in 2020 a training school MERADE 2(MEasurement of RADioactivity in the Environment: focus onNoRs, NORM and Radon)

Medium-term (3-5 years) prospects

LabExpoRad is a partner in a strategic program in the area of Higher Education, called "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.

As one of our aims is to be a reference laboratory, we are also developing a Support Office whose main objective is to clarify doubts on ionizing radiation issues, particularly in regard to radon, mitigation measures, assistance to public and private clients, who need information on environmental radiologic contamination. A support internet site https://labexporad.wixsite.com/home is under development.

One of the challenges posed to the research team, was the elaboration of a project in partnership with the Portuguese Lung Foundation which goal is to assess radon exposure of patients that present this different kind of adenocarcinomas. The present Portuguese authority for radiation matters is the Agência Portuguesa do Ambiente (Portuguese Environment Agency). On what concern radon the Agency is organizing a national network. Our laboratory LabExpoRad will be an active part of this network.

Another line of research being prepared is the study of stem cells from mice exposed to radon-containing atmospheres and also the study of the biological effects caused on aromatic plants, used for human consumption, when exposed to saturated atmospheres with radon gas.

SWOT analysis

Strengths

Development of instrumentation with application outside academic environment, well equipped laboratory.

Weaknesses

Small team.

Opportunities

Collaboration with other national and international institutions and laboratories. Transposition of Basic Safety Standards COUNCIL DIRECTIVE 2013/59/EURATOM to national legislation.

Threats

Lack of solid financing.

Radiation, health and environment

Publications

6 International Conference Proceeding(s)

- *"Does radiation exposure at the workplace affects worker's happiness and satisfaction? A European perspective"*, S. Soares, D. Pereira, M. Marques , 8th EUTERP Workshop Optimizing radiation protection training, Qawra, St. Paul's Bay, Malta, April 10-12, pp. 50, SCK•CEN-BA-120 | SCK•CEN/32779893
- *"Preliminary analysis of the radon concentration in waters of the Municipality of Bibala, Angola: Implications on public consumption"*, J. Kessongo, Y. Bahu, P. Almeida, L. Peralta, S. Soares, 3rd International Conference on Dosimetry and its Applications (ICDA-3), pp.01.3, Lisboa 27-31 maio 2019
- *"Evaluation of the Radon Exposure Potential in Buildings in the Municipality of Lubango"*, J. Kessongo, Y. Bahu, P. Almeida, L. Peralta, S. Soares, 3rd International Conference on Dosimetry and its Applications (ICDA-3), pp.01.4, Lisboa 27-31 maio 2019
- *"A low-cost radon monitor"*, Soraia Elísio e Luis Peralta, 3rd International Conference on Dosimetry and its Applications (ICDA-3), Lisboa 27-31 maio 2019
- *"Teaching radon and environmental radioactivity: an experience in the frame of an Erasmus + European partnership"*, C. Licour, I. Gerardy, S. Schreurs, S. Soares, 9th International Conference on Protection against Radon at Home and at Work, Prague, Czech Republic, 16 - 20 September, pp. 29
- *"Radon exhalation rate measurement from granite samples"*, S. Soares, Y.Bahu, J. Kessongo, L.Peralta, 9th International Conference on Protection against Radon at Home and at Work, Prague, Czech Republic, 16 - 20 September, pp. 98

2 Internal Note(s)

- *"Development of a low-cost monitor for radon detection in air "*, Soraia Elísio e Luis Peralta, arXiv:1907.08143
- *"Radon Concentration Potential in Bibala Municipality Water: Consequences for Public Consumption"*, Joaquim Kessongo, Yoenls Bahu, Margarida Inacio, Pedro Almeida, Luis Peralta, Sandra Soares, arXiv:1908.03140

Presentations

9 Oral presentations in international conferences

- Yoenls Bahu: *"Evaluation of the Radon Exposure Potential in Buildings in the Municipality of Lubango"*, 2019-05-28, 3rd International Conference on Dosimetry and its Applications (ICDA-3) , Lisboa
- Yoenls Bahu: *"Preliminary analysis of the radon concentration in waters of the Municipality of Bibala, Angola: Implications on public consumption"*, 2019-05-28, 3rd International Conference on Dosimetry and its Applications (ICDA-3), Lisboa
- Luis Peralta: *"A low-cost radon monitor"*, 2019-05-28, 3rd International Conference on Dosimetry and its Applications (ICDA-3), Lisboa
- Yoenls Bahu: *"Preliminary analysis of the radon concentration in waters of the Municipality of Bibala, Angola: Implications on public consumption"*, 2019-05-28, 3ª International Conference on Dosimetry and its Applications, ICDA3, 2019, 27 – 31 May, Lisboa, Portugal
- Yoenls Bahu: *"Evaluation of the Radon Exposure Potential in Buildings in the Municipality of Lubango"*, 2019-05-28, 3th International Conference on Dosimetry and its Applications, ICDA3, 2019, 27 – 31 May, Lisboa, Portugal
- Sandra Soares: *"Radon exhalation rate measurement from granite samples"*, 2019-09-16, 9th International Conference on Protection against Radon at Home and at Work, 2019, 16 - 20 September., Prague, Czech Republic
- Sandra Soares: *"Teaching radon and environmental radioactivity: an experience in the frame of an Erasmus + European partnership"*, 2019-09-20, 9th International Conference on Protection against Radon at Home and at Work, Prague, Czech Republic
- Conceição Abreu: ***"A Fisica para um desenvolvimento equilibrado",*** 2019-05-30, 3ª Conferência de Fisica dos CFPLP, S. Tomé
- Joaquim Pedro Kessongo: ***"AVALIAÇÃO DO RISCO DO RADÃO PRESENTE NA ÁGUA POTÁVEL DO MUNICÍPIO DA BIBALA",*** 2019-05-30, 3ª Conferência de Física dos dos países de Língua Portuguesa: A Física para o desenvolvimento equilibrado., S. Tomé

2 Presentations in national conferences

- Sandra Soares: *"Radioatividade Natural Associada ao Radão"*, 2019-01-24, IX Congresso da Fundação Portuguesa do Pulmão, 2019, 4 January, Auditório dos Serviços Sociais da Câmara Municipal de Lisboa, Lisboa, Portugal

  Sandra Soares: *"Radioatividade natural associada ao Radão/O Projeto SOS Radão"*, 2019-06-22, VIII Encontro de Pneumologia Oncológica da Guarda, 2019, 22 de junho, Biblioteca Eduardo Lourenço, Guarda, Portugal

3 Oral presentations in international meetings

- Sandra Soares: *"Do workplace environmental conditions affect worker's absenteeism and job satisfaction? A European perspective"*, 2019-04-12, 8th EUTERP Workshop Optimization of training in radiation protection, 2019, 10 – 12 April, Qwara, St Paul's Bay, Malta
- Sandra Soares: *" Characterization of radon exhalation from building materials"*, 2019-06-04, 15th Workshop on European Collaboration for Higher Education and Research in Nuclear Engineering and Radiological Protection (CHERNE), 2019, 02 – 04 June, Portopalo di Capo Passero, Catania, Italy
- Sandra Soares: *"Radon Specific Activity Assessment and Exhalation Rate Measurement from Building Materials"*, 2019-09-04, NovaBiophysica, 2019, 04 - 06 September, Lisboa, Portugal

Theses

3 PhD

- Margarida Isabel Inácio: ***"Bioacumulação dos descendentes diretos do radão nas folhas de Nasturtium officinale",*** 2014-01-01 , (ongoing)
- 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)

1 Master

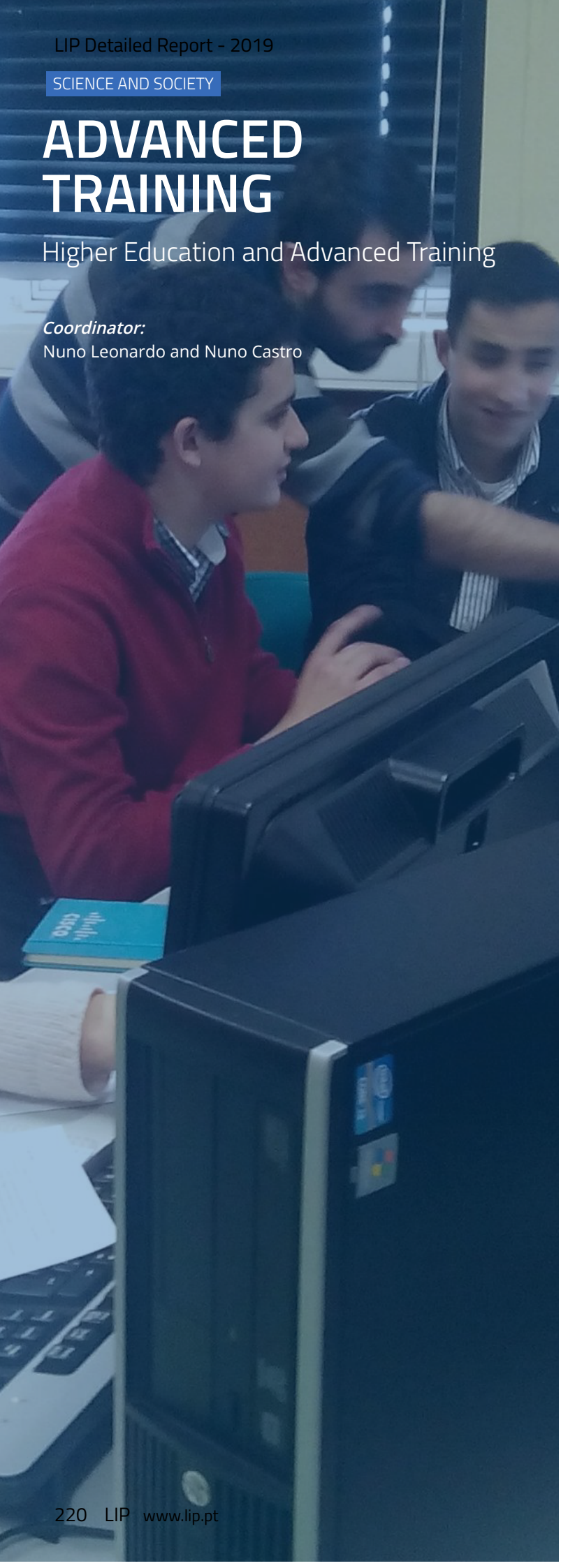
- Soraia Elísio: ***"Development of an active Detector for Radon Detection in air",*** 2018-09-01 / 2019-05-31, (finished)

SCIENCE AND SOCIETY

ADVANCED TRAINING

Higher Education and Advanced Training

Coordinator:
Nuno Leonardo and Nuno Castro



Overview

LIP has a long standing experience in advanced training, and permanently hosts tens of PhD, master and bachelor students, who actively work within LIP's research groups. In each of its three nodes, the Laboratory works in close relation and cooperation with the 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 are 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;
- Ensure high-quality graduate training: support baseline core training and adequate guidance of LIP graduate students; support national and international PhD programmes and networks in our fields of activity.

Advanced Training

Last year activities

In 2019, a wide set of activities for undergraduate and graduate students was carried out, as briefly described below.

Undergraduate students

LIP Internship Programme: In 2019, the programme had its third edition and is now a well-established, flagship activity of LIP. About 60 students participated during the summer period, involving about all research groups across the three LIP nodes. The programme included a preparatory week (lectures and hands-on tutorials), a research project of variable duration (from two weeks to two months), and a two-day final workshop in which the students presented their work. Lectures were complemented with thematic discussions, involving one researcher and few students, held locally at each node. Also newly introduced this year were the so-called "August chats": in between the July introduction week and the September workshop, using the traditional LIP Seminars slot, there were informal gatherings where the students briefly introduce themselves and their research project to their fellow students, and picked one specific problem or challenge they were addressing to be discussed. Yet another novelty was the possibility that was offered to students in this edition to describe their work in the form of a scientific paper, with 5-10 pages long in a prepared format, a challenge that was readily taken by several students. The programme counted with a broad participation of LIP researchers, who served as project supervisors, delivered tutorials and lectures, guides topical discussions, and attended and contributed to the discussion at the final workshop. This year again, an online anonymous survey was conducted amongst the students. The results were globally very positive, and will continue to be taken into account in the organization of the following editions. A fraction of the students who attend the program systematically remain engaged in further research at LIP. Such connection to LIP is kept either shorter-term, with the goal of completing a specific goal related to the project (a publication, a software tool, an analysis result) or using their research work to fulfill academic duties such as a project for an undergraduate course; or longer-term, enrolling in a master degree or PhD programme. This is reflected in particular as a clearly noticeable increase in the the number of master theses defenses based on research performed at LIP. The dissemination of work carried out by the students themselves (in the form of videos where students expose their research topic, of student research papers, and thesis documents) is actively supported.

Schools & workshops: LIP is involved in several regular school and workshop series directed at undergraduate students, which include lectures, hands-on exercises, and introductory overviews of ongoing research activity at LIP.

- In 2019, the 5th edition of the Lisbon mini-school in particle and astroparticle physics, co-organized by LIP and CFTP, was held in Costa da Caparica in February and gathered 30 undergraduate students from several universities.
- The 2019 Particles and Light hands-on workshop, held in July at FCUL and IST, counted with the participation of 11 students.
- The 2nd edition of the Data Science school and symposium was held at LIP-Minho in March. The event had the double goal of providing advanced training and establishing and consolidating links with other institutions and particularly with the non-academic sector through this field. The school had about 80 participants, and the symposium 114 participants, with representation from 20 companies. A public session was held by Glen Cowan (Royal Holloway) which was attended by over 100 people. This became a regular event series, and will be held again at LIP-Coimbra in March 2020.

Outreach for undergraduates: Besides training events, LIP conducts a number of initiatives with the goal of making LIP and particle physics known and attractive among undergraduate students. The LIP control room at IST is meant to be a meeting point between IST students and LIP researchers, mainly those teaching at IST but not exclusively. Sessions introducing detectors and physics topics have been held, and a display with LIP related news and announcements has been installed. Auger control shifts and CMS data quality shifts take place. Furthermore, LIP regularly participates in events organized by physics student associations at the different universities. In 2019, the National Physics Students gathering (ENEF'2019) took place at IST, and in this context over 60 students overall were received at LIP. In addiiton, 11 students from FCUL visited LIP. The visits were hosted by researchers from different groups, and further offered the opportunity for studens to interact directly with master and doctoral students at LIP.

Graduate students

Various actions are directed towards the PhD and master students working at LIP, and also in the framework of international PhD programmes. During 2019, LIP hosted over 80 graduate students. Furthermore, LIP coordinated the FCT doctoral programs IDPASC (Particle Physics, Astrophysics and Cosmology) and DAEPHYS (Doctorate in Applied Physics and Physics Engineering), and the IDPASC international network. LIP is a member of AMVA4NewPhysics, a EU funded International Training Network, and hosts a PhD student in this context.

The following events and activities took place in 2019:

9th IDPASC international School: held in Otranto, Itay, from May 28 to June 9 2019, and was organized jointly with the XXXI INTERNATIONAL SEMINAR of NUCLEAR and SUBNUCLEAR PHYSICS "Francesco Romano". The school included lectures, discussion sessions and a nal exam. Over 20 students participated.

5th LIP/IDPASC PhD Students Workshop: for two days, all students presented the status of their work to an audience of graduate students and researchers, in Braga in July. Keynote lectures on selected topics were also part of the program, including transferable skill lectures on subjects suggested by the students themselves.

2nd School on Data Science in (Astro)Particle Physics: three days with lectures on statistics and machine learning and a strong emphasis on hands-on problems. Tutorials and a data challenge were held. Around 80 students participated. As mentioned bove, the school was followed by a symposium where the academic and corporate communities discussed common problems and approaches in data science.

LHC Physics Course: about 18 lectures covering introduction to the standard model, detectors, statistics, and overall research were proposed, from March through June. The course has a nal evaluation and now gives credits to PhD students at IST. The course is addressed to a specialized/narrow set of master and PhD students. In 2019, 3 students completed the course and took the nal exam.

Computing tutorials: on Linux (Braga, 20 hours of theory and practice, 15 participants), Git & GitLab (Lisbon, 20 attendees), Keras, Docker, etc. (Braga, Coimbra and Lisbon, via video-conference, 10 regular participants).

LIP Seminars, regularly held in the three LIP nodes.

"SciCom with and for Students": This project has the double goal of involving LIP's PhD and master students in outreach activities, enhancing their communication capabilities via formal training and practical experience, while promoting a better integration, as it is a way of getting the younger members of the different groups to know each other and to work together, promoting communication and team spirit. LIP's PhD and master students are thus offered public speaking training (on a volunteer basis) and invited to participate in a public session for schools hosted by the students themselves. In 2019,this happened on UN's International Day of Women and Girls in Science. Two consecutive sessions were held, gathering around 140 high-school students.

Support to FCT's programmes for advanced training in international organizations: since several years LIP supports the FCT programme "Advanced training of engineers in the International Organizations - CERN, ESA and ESO", now with a separate call for CERN. LIP encourages the groups at CERN to prepare and submit job description proposals (with the participation of Portuguese institutions and/or in key areas of interest to Portugal, as de ned by FCT), helps disseminate the calls, particularly through our networks and partner universities and participates in the selection process of the candidates. Very positive feedback from supervisors is testimony to the importance and success of this programme.

Prospects for next year

The first goal of LIP's advanced training group for 2020 remains to consolidate the existing engagement events, training activities and support actions towards undergraduate students in Physics and Engineering, graduate students at LIP, and graduate students engaged in PhD programmes and networks coordinated by LIP. In fact, many new tasks have been recently initiated and human and material resources are limited. At undergraduate level, the flagship initiative is clearly the summer student programme, and also the development of a small set of activities that has the double goal of attracting students to the internship and of providing regular opportunities for contact after the internship. At graduate level, priorities are to achieve a closer and more effective follow-up of LIP's students, with regular students workshops, surveys and a close interaction with the LIP Student Council. Support opportunities for student work dissemination. The path of involving students with LIP and with ECO activities will be pursued.

Some of the foreseen key initiatives foreseen for 2020 are listed below:

LIP Internship Programme: to pursue this integrated LIP programme is a priority for 2020; this builds on the success attained and experience acquired in the previous years to continue to make improvements and implement further engaging actions.

Schools & workshops for undergraduates: namely with the 6th Lisbon Mini School on Particle and Astroparticle Physics, organized by LIP and CFTP, to be held in Lisbon in February; the Data Science School and Workshop, to be held in Coimbra in March, and emphasizing connection to and partnership with industry; and Particles and Light workshop series, focused on hands-on work and organized jointly at IST and FCUL, and by participating on a regular basis in events organized by the universities.

Graduate students: among the already foreseen initiatives are: Joint IDPASC and LIP student workshop; 2020 IDPASC international school, to be held in Nazaré, Portugal; LHC physics course; plus a series of regular seminars and tutorials. Keep a close interation with LIP's student Council, to work jointly to attend to students' needs and assist in implementing their ideas.

Already in the beginning of 2020 FCT and LIP agreed to promote a program of PhD grants in particle physics and related scientific and technological domains relevant for the Portuguese participation at CERN. In 2020, two calls will be opened, in February and September, and in each of them two domains will be considered: Particle and Astroparticle Physics and associated scientific domains; Technologies associated to the Portuguese participation at CERN and their transfer to society.

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 long experience and high reputation of LIP as a host institution and of LIP researchers as highly committed supervisors.

Weaknesses: The fact that part 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. The lack of manpower for activity implementation.

Opportunities: The success of the activities developed in the last couple of years has already resulted in a greater visibility of LIP among university students and beyond. Opening positions at universities is starting to strengthen their links with LIP.

Threats: The risk that the multiplication of activities, together with the lack of manpower, result in poorly organized events that damage LIP's achieved reputation.

References

LIP Internship Program public page, http://www.lip.pt/training/summer-student-program/

LIP Internship Program, agenda 2019, https://indico.lip.pt/category/62/

LIP Internship Program book of abstracts, LIP News Bulletin, issue 17 http://www.lip.pt/outreach/lipnews/pdfs/issue17_pt.pdf (http://www.lip.pt/outreach/lipnews/pdfs/issue15_pt.pdf)

Student videos, https://www.lip.pt/?section=training&page=share-students-project-videos (https://www.lip.pt/?section=training&page=share-students-project-videos)

LIP Data Science, school and symposium, https://www.lip.pt/data-science-2019/

Note: Several of the events foreseen for the first semester of 2020 had to be canceled or postponed due to the COVID-19 crisis.

SCIENCE AND SOCIETY

ECO

Education, Communication and Outreach

Coordinator:
Catarina Espírito Santo and Pedro Abreu

Overview

Education, Communication and Outreach (ECO) are today a fundamental aspect of the activities of a research and development institution. This results from the recognition that ECO activities are both part of our social role and essential for the recognition of our work's relevance; and that such activities help attracting funds, partnerships, opportunities and human resources — both students and researchers.

The LIP Education, Communication and Outreach group (LIP-ECO) was created in 2016 with the aim of better organizing and extending the ECO-related activities carried out at LIP. LIP's communication strategy document was then written, and priority target audiences were de ned: our peers (universities, research centres and funding agencies); the LIP community (internal communications); undergraduate students in Physics and Engineering; the school community. A core team with weekly editorial meetings and a clear activity plan has been established. Presently, we are still focusing in these priority audiences. Having as background the communication strategy document, activity plans are prepared for each academic year. The activities of LIP-ECO involve all three LIP nodes, which are represented in the core team and/or in local coordinations. They are developed in close collaboration with the LIP Computing Group, namely in what concerns the sharing of human resources and technical means. Furthermore, they are transversal activities, which depend upon the collaboration of all the groups.

LIP has several national and international partners in communication, outreach, and support to education. At national level, we are partners of Agência Ciência Viva, the Portuguese Physical Society (SPF), and have a close collaboration with several schools. LIP is part of the International Particle Physics Outreach Group (now IPPOG collaboration), 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 teacher programmes.

ECO

Last year activities

1. Communications

1.a External communications

FCT Evaluation: The evaluation of all R&D units initiated in 2017 by the Portuguese Foundation for Science and Technology (FCT), which will define the lab's level of public funding for the next five years, was finally completed in mid 2019. LIP-ECO provided essential support to the preparation of the visit of the LIP premises of the evaluation panel, including in the preparation of the presentation about LIP given to the panel by the president of the unit.

LIP yearly reports and plans: LIP-ECO is responsible for the edition of LIP's yearly reports and plans. The detailed activity report and plan is meant to give a complete, detailed view of the laboratory's work and achievements, aimed at LIP's associates, our International Advisory Committee, and LIP members, and fulfills a legal requirement. The public report gives an overview of the laboratory's activity aimed at partner institutions and the general public. This year, there was an effort to increase the involvement of the research line representatives in the Scientific Council Coordination Commission, in particular participating in the writing of the research line texts for the public report. Technically, there was important work done by members of the computing group in the tools exporting the information on the LIP database both to the web site and to the detailed report, and also to adapt those to the changes in the group structure of LIP.

LIP-News Bulletin: The LIP-News Bulletin is LIP's periodic publication. It is primarily a printed magazine, although it can be found in an online repository. It is meant for a relatively wide audience ranging from researchers from our partner universities and research institutes to physics teachers, last years secondary school students and general public interested in science. In the last few years, we made an effort to consolidate the Bulletin, aiming at publishing only two issues per year but with a a stronger editorial plan, a wider group of authors, both from LIP and invited authors, thus more pages and a more careful graphical work. Due to severe lack of manpower and some unexpected delays, one issue was published in mid 2019, as planned but the next issue (including the tribute to Gaspar Barreira) will come out only in 2020.

LIP web site: The new LIP web site (released in 2016/2017) continued to be developed and upgraded. Important aspects in 2019 were a general check/update of the information related to the research groups, which was particularly important in the context of the evaluation, and also of the recruitment of students for the summer internships. Technical work to provide easier access by the group members to group (and personal) LIP pages in ongoing and expected to be completed site. The site news and event lists are now rather dynamic and now more closely related to the social media.

Social networks: LIP is present in the social networks Facebook, Twitter and linkedin. The publication in the LIP-News Bulletin of the social network statistics (in particular, top-10 of most popular posts) is a way of information crossing between different channels and systematically collecting evaluation information. In 2019, a new member of the group (PhD student Ana Sofia Inácio) took over the charge of managing LIP's social media. She further developed some projects aimed at increasing the participation of members of the different LIP groups in communications, and fostering the production of contents to the social media. Two projects should be highlighted:

- Celebrating the International year of the periodic table, each Friday an enigma was posted about an element, in its relation to particle physics, and to answer was provided on Monday. Many LIP members contributed, and every week we got answers from our followers.
- Preparation of a series of short video interviews with women who are LIP researchers. Several are under preparation, and the first one has been published already in 2020 in UN's International Day of Women and Girls in Science.

Press/media: Although this is not chosen as a priority, we do contact the media and do the follow-up of subjects both related directly to LIP or to CERN and the experiments we are part of. Most articles came out in LUSA (the national news agency) and Público (a reference national daily newspaper). LIP also started its participation on "90 seconds of science", a daily science broadcast on a national radio channel. Some examples below:

- The birth of the Southern Wide field-of-view Gamma ray Observatory (SWGO) Collaboration, after the Lisbon meeting in May (Público 2019/07/01)
- VIP and industrial visits to CERN (Público 2019/09/04)
- One of many articles of tribute to Gaspar Barreira (Público 2019/09/10)
- General CERN news:
  - FCC (Público 2019/01/16)
  - Next CERN DG (Público 2019/11/07)
  - Higgs discovery in the top-ten events of the decade (Público 2019/12/15)

- LIP in "90 seconds of science" radio-broadcast:
  - Mário Pimenta, October 2019
  - Patrícia Gonçalves, November 2019

Science communication talks in conferences:
The co-coordinator of LIP-ECO (CES) was co-convener of the Communication, Outreach and Diversity Session in the 2019 EPS-HEP conference, in Gent. A team member (SA) presented a communication on the 10 Years of the CERN Programme for Teachers in Portuguese in EPS-HEP (see references), and also in the Physics Conference of the Portuguese Speaking Countries Community (CPLP), held in S. Tomé e Príncipe.

Branding, communication materials and merchandising:
The work towards communicating a coherent image of the lab, making useful materials available to the LIP community (logos, templates, image sets, branding products) has been continued, although we are still behind schedule due to lack of manpower. Besides the flyer introducing LIP re-done in 2018, we now have a roll-up introducing LIP, equipment to produce pins and badges and outreach objects (mainly games and books from CERN) that can be used when participating in fairs and other public events. Progress in ongoing in the basic design work for producing some limited merchandising (mainly pens and notebooks) and in the drafting of the graphic standards guide.

1.b Internal communications

Following the recognition of internal communications as a priority for LIP-ECO and the conduction of an internal survey on LIP's internal communication tools and procedures, several tools were developed in 2018 and already fully operational in 2019. Examples are:

cLIP digital newsletter: A digital internal newsletter with the motto "Widening participation for better communications at LIP" was issued monthly starting in March 2018 to convey organizational information to LIP members, scientific highlights of the work of the different groups, and the participation of the groups in ECO activities. This year, links to the summaries of the directorate meetings both in Portuguese and in English were added.

LIP intranet: The new LIP intranet also released in 2018 contains more complete practical information and information for newcomers; easier access to documentation, such as regulations, reports, etc; a more complete agenda of events of interest for LIP collaborators and info on communication (templates, logos, how to participate). Important work on user authentication was performed by the Computing Group, which will improve accessibility and security in the LIP web domains is still ongoing.

Standard organizational and bureaucratic procedures:
Efforts were made towards a more systematic use of the new user registration form, event registration form (to request the support of the LIP central administration, computing and ECO services on the organization of events with the involvement of LIP groups or members).

LIP-News Bulletin: An effort was made to foster the participation of the LIP community, further using the Bulletin to cross information between the groups, introduce people, and spread information on organized events and achievements, and interconnect the different nodes.

On the other hand, specific efforts were continued to foster the participation the the LIP community on ECO activities. Namely:

Science Communication training: Once more, a one-day workshop on speaking in public with a recognized expert in the field was offered to the LIP community. We encouraged in particular PhD and master students to participate. The results of the satisfaction survey were very positive.

Fostering participation in ECO: On the intranet, there are more clear instructions on how to participate, with information on the different channels and ongoing campaigns, shared files and template materials. Announcements of the newsletter and by email spread different participation opportunities. For the public, a list of proposed talks for schools on the public website was crucial to have a wider number of people participating. While participation has clearly increased, asymmetries between the different groups are still large.

Communication with and for students: this a program already highlighted last year and which we consider of particular relevance. It offers LIP's graduate students theoretical and practical training on science communication, while at the same time puts students from different groups to work together, promoting internal communication and team spirit.

Nevertheless, internal communications are still felt as an aspect that needs to be improved at different levels. While not all of them are directly related to ECO, the ECO group clearly has an important role in promoting initiatives and forums that can help improve the situation.

2. Education and outreach

During the past year, we combined the continuation of well-established education and outreach programmes, which are today flagship activities of LIP, with the consolidation of projects started in the previous year, concerning mostly collaborations with schools on more hands-on projects and science clubs.

IPPOG's International Masterclasses in Particle Physics: Under the coordination of LIP, about 1700 participants gathered in 15 sessions all over the country: Aveiro, Beja, Braga (2 sessions), Bragança, Coimbra, Covilhã, Évora, Funchal (Madeira), Lisboa (2 places, 3 sessions), Ponta Delgada (Azores), Porto, Vila Real, and with our remote support in São Tomé and Príncipe.

Summer internships for high school students: In the framework of Ciência Viva's programme "Science in the Summer", LIP has proposed several internships in Lisboa and Coimbra and hosted close to 14 students to learn about experimental particle physics and directly experience the work of scientists in the field. Within the internship's programme of the University of Coimbra, LIP further hosted 13 students for one week in internships devoted to the ATLAS experiment at the LHC and to dark matter searches.

CERN Portuguese Language Teachers Programme: Under the responsibility of LIP and with support from CERN and Ciência Viva, the 13th edition of the school was held in the beginning of September, attended by 20 Portuguese teachers, 20 Brazilian teachers and 2 Angolan teachers. In this edition, it was again not possible to obtain enough support to bring more teachers from Portuguese-speaking African countries. Efforts to re-establish this participation in the next editions will be continued. Over the last decade, more than 720 teachers attended the school. An online survey was conducted, which was used as the basis for conference presentations (see refs) and has shown a high level of appreciation.

Seminars in schools: More than 70 outreach talks were given by LIP scientists in schools, mainly in the areas of Braga, Coimbra and Lisboa but also occasionally in other places. The creation of a list of talks proposed to schools, available on the outreach section of the LIP website, allowed for a greater diversify of subjects and speakers that actually go to schools, and to have more schools into the loop.

Special outreach events: A few special outreach moments are highlighted below:

- The UNESCO's **International Day of Women and Girls in Science** was celebrated by inviting secondary school students and teachers to a public session presented by PhD and master students from LIP, with the title "Particles: from the Universe to the Laboratory". The team had 3 female students and 3 male students from different groups. We had so many requests that we had to present two consecutive sessions, hosting 140 participants that provided very positive feedback. This session was part of our Communication with and for Students programme.
- The **school "How to become an astronaut"** at the Astronomical observatory of the University of Coimbra, co-organized by LIP, hosted 35 students during five days.
- In 2019, LIP participated in the **European Researchers Night at Braga, Coimbra and Lisboa**. At Forum Braga, visitors built detectors and searched for particles in the city. At the Science Museum of the University of Coimbra, there was time to see cosmic rays and to learn about how positron emission tomography works. In Lisbon, we profited of the Planetarium Calouste Gulbenkian to host more than 150 participants, who traveled to CERN on a virtual visit to the CMS experiment and saw the passage of charged particles in cloud chambers, set up for the event.

In addition, around 300 students visit LIP-Coimbra every year.

The LIP-EduLab: It is a goal of LIP to go further on the support to education activities, creating the conditions to propose more laboratory-oriented activities. Equipping the laboratory will require a certain level of dedicated funding, and also to pursue the efforts for the in-house development of equipment for educational purposes. The adaptation of SW and HW already developed for other purposes in certainly a way to go. The scientific infrastructures and competence centres of LIP will play an important role.

In the school year 2018/2019, the LIP-EduLab initiated a pilot phase, and was tested first in Ciência Viva summer internships (12 students) and later in the framework of a partnership with two schools in Lisbon (about 20 students), which involves both introductory lectures, research work on particle physics subjects and several work sessions at the lab along the year under the programme "Cientificamente Provável" (coordination: F. Barão). In addition, support was given a school in Lisbon and another one in Minho in the development of projects proposed by the students and teachers and developed in the schools. There was a close collaboration between Minho and Lisboa, working towards similar goals, and some support from LIP infrastructures both in Coimbra and in Lisboa. Expertise in python programming and Raspberry Pi use was explored, and several simple cosmic muon detectors were built or assembled, or are currently being completed.

In the school year 2019/2020, we decided to concentrate on the development of the laboratory itself, equipping it with new material and projects, with less direct contact with high-school students but a wider team at LIP and the participation of the most motivated teachers. Contacts with students happen through visits to LIP (talk + cloud chamber building workshop) and through the support to projects under development in the schools by the involved teachers. The set of cloud chamber kits now available was built in 2019, in partnership with the science club "Física das Coisas" from a school in Lisbon, coordinated by teacher Luís Afonso, who is now part of the EduLab team.

Development of equipment and tools for education and outreach: This is an ongoing effort pursued by LIP since long, using mainly the competences existing in LIP's scientific infrastructures, but severely limited by manpower availability. An example is the widely known LIP spark chamber, designed and built at LIP-Coimbra (coordination: L. Lopes, A. Blanco) or, more recently, the cloud chamber developed at LIP-Coimbra (coordination: F. Neves, see Dark Matter Group).

Concerning the specific competences existing at LIP-Minho (multimedia, virtual reality, etc., coordinator: H. Carvalho), the work is progressing but, again, at a slow pace due to other commitments. A powerful 3D event display of the Pierre Auger Observatory was developed and used for demonstrations in outreach events, and is now available publicly available. It is now also be used for visualization and analysis of the Auger public data, available for educational purposes. For this purpose, virtual reality goggles are now available at LIP-Minho (and on the other nodes when requested) and the Pierre Auger Observatory bought two pairs for its Visitor Centre.

RPCs for outreach and the MuTom project: In particular, the use of RPC-based detectors for educational purposes is being pushed forward (coordinator: L. Lopes), namely within the framework of the MuTom project, which has a prototype in the Lousal mine, now a science center in southern Portugal (see elsewhere is this report). The project has great outreach potential, and already in 2019 we prepared online and printed material (web site, flyer) and seminars in schools or at Lousal, followed by visits to the mine, have been carried out in the framework of the "Ciência Viva in the Summer" programme.

Other partnerships with schools: in the scope of the call for science clubs at the school jointly launched through Agência Ciência Viva by the Ministry of Education and by the Ministry of Science, Technology and Higher Education ("Clubes Ciência Viva"), LIP established partnerships with six schools spread all over the country. The compromise for LIP is to go to the school, talk to the students, organize Cloud Chamber Workshop, and/or help to prepare activities similar to those developed in the LIP-Edulab programme specified above. LIP gave logistic support to Portuguese schools organizing visits to CERN or participating inthe CERN Beamline for Schools competition.

Other activities: LIP collaborates regularly with the Portuguese Physics Society (SPF), of which it is as a collective associate. Several of its members serve in the management of the Society and as conveners of its Particle Physics Division, or contribute on a regular basis to SPF's magazine. In the scope of this collaboration, LIP has participated in the 3rd Physics Conference of the CPLP (Community of Portuguese Speaking Countries), in a meeting of the Science and Technology focalpoints celebrating UN's Day of Science for Peace and Development, and in the launch of the Portuguese Speaking Countries Physics Society.
Together with SPF, LIP updated and developed new modules for the exhibition "The light deviated by the Sun", which was inaugurated in the framework of the Eddington@Sundy initiative to celebrate the centenary of the experimental proof of General Relativity, and will be the basis of a permanent science centre in São Tomé e Príncipe.

Conferences

- Sofia Andringa, Oral presentation ***"A Física do presente e futuro",*** 3ª Conferência de Física da CPLP - A Física para um desenvolvimento sustentável", São Tomé, São Tomé e Príncipe, May 2019
- Sofia Andringa, Oral presentation ***"Particle Physics in a Common Language - the CERN Portuguese Language Teachers Programmes",*** EPS-HEP2019, Ghent, Belgium, July 2019
- Pedro Abreu, ***"Escola de professores no CERN em Lingua Portuguesa",*** Oral presentation at the "Celebration of the UN's World Day of Science for Peace and Development – Physics for a sustainable development", Headquarters of CPLP, Lisbon, November, 2019
- Catarina Espírito Santo was co-convener of the ***"Outreach, Education and Diversity"*** session of the international conference "EPS-HEP'2019, Ghent, Belgium, July 2019

Exhibitions

- Sofia Andringa, Preparation/update of the Exhibition ***"A Luz desviada pelo Sol"*** for the 100th anniversary Sir Arthur Eddington observation in the island of Príncipe, São Tomé e Príncipe, at Roça Sundy - Eddington@Sundy; participation in the design, construction and commissioning of a module featuring a Michelson Interferometer installed at the museum "Espaço Ciência Sundy", May 2019.

Publications

- ***"Um ano na fronteira do infinitamente pequeno",*** Sofia Andringa, Nuno Castro, Ricardo Gonçalo and Orlando Oliveira, volume 41 - 3/4, 2019
- ***"A Física para um Desenvolvimento Equilibrado - 3CFPLP",*** Mª Conceicao Abreu, Gazeta de Fisica, vol 42 fasc 3, 2019
- ***"Celebração do Dia Mundial da Ciência para a Paz e o Desenvolvimento - A Fisica para um Desenvolvimento Sustentavel",*** Mª Conceição Abreu, Gazeta de Fisica, vol.42 fasc4/5, 2020
- ***"Criação da União dos Físicos dos Países de língua Portuguesa - UFPLP",*** Mª Conceição Abreu, Gazeta de Fisica, vol 42 fasc4/5, 2020

Prospects for next year

In 2020, the consolidation of the activities and services already provided to the LIP community and to the public remains a priority, as human and material resources remain very limited. The consolidation of the nation-wide nature of the LIP-ECO group, by strengthening the collaboration between the three LIP nodes is certainly a crucial aspect, and the nomination of local coordinators is an important step forward. Dedicated efforts to reinforce the available resources must be pursued. This means keeping the efforts to involve the LIP community, in particular the students and young researchers, but also actively looking for funding opportunities, and to exploit the possibility of hosting, in internships with the duration of a few months, master students in science communication, design or other ECO-related subjects.

Regarding our international participation, the former LIP Representative in IPPOG (Pedro Abreu) was elected Co-Chair of the IPPOG Collaboration, and new representatives were nominated for IPPOG (Ricardo Gonçalo) and for EPPCN (Catarina Espírito Santo). In both the Collaboration and the Network LIP is participating and will continue in the dedicated sub-group following the development of European Strategy of Particle Physics Update and its needs related to education, communication and outreach issues.

1. Communications

Externally, the main goal of communications is to support the priorities of the laboratory, particularly in what concerns funding and scientific employment. The key questions are: what can ECO do to ensure visibility by the right publics in the right moments during 2020? What are the relevant messages and the adequate channels to spread them? We are focusing on the communication on fundamental particle physics: the LHC high-luminosity phase and the future European Strategy, our participation in the R&D and construction of world leading particle and astroparticle physics experiments, and the strengthening of the theory side at LIP. At the same time, some application and technology areas will be very important to communicate in 2020: proton therapy with the recent creation of the ProtoTera Association in Portugal; Scientific Computing for which LIP has an important role in the country and the growing expertise on data science and big data, and LIP activities connected to Space, now that a Portuguese Space Agency has been created.

The expected call for the renewal of the "Associated Laboratory" statute announced by FCT, if confirmed for 2020, will surely impact on the work of the communications team, who will support the management and the administrative services of LIP.

Looking back at LIP's communication strategy document drafted in 2016, and in particular at the priority audiences then defined, we considered that while the main objectives are being achieved in what concerns stakeholders and undergraduate students; there is, however, still much to do towards our peers (universities and research centers) and also in internal communication, in close coordination with the management. In the first case, the effort has to be done strengthening our links to the relevant departments, to the student associations and to the communication offices. The role of the contact LIP researchers in each university should be strengthened and more clearly defined, making sure that we continue to be present in all the events they organize (which is sometimes a great effort, due to lack of personpower and short notice warnings), and increasing the visibility of LIP in the communication channels, both online and printed.

In what concerns internal communications, that challenge is still there, and the fact that LIP is split in three nodes make it bigger. There is a need to change the communication patterns of the LIP community. And while the already existing or recently created communication could be better explored, the question goes much beyond that and probably requires the creating of new forums, both for open discussions on management and institutional issues and, on the other hand, for informal contacts, reinforcing the links between people and the lab culture. While this goes much beyond the ECO group, mas LIP-ECO should have a role in pushing for the discussion and helping to put in practice some of the ideas.

In 2020, the work in the wide set of tasks concerning institutional communications will be pursued. New projects and developments will depend on the human resources, which are currently very low. While it is very important to encourage the LIP community to participate, some way of having more dedicated personpower should be found. This would allow to progress on ideas that have been waiting for long: the preparation of templates, standard presentations and a document with graphical rules useful for LIP people; the production of promotion material, such as a video introducing LIP (the first of a set of videos in the several research areas); more detailed flyers; simple merchandising or contents developed for printing or for the social media.

Still, and to finish with a more positive note, there might be some space to extend our reach slightly towards the non-priority audiences: the general public, starting with simple outreach sessions in different settings, and the media, relying in the collaboration with our partner universities.

2. Education and outreach

During the past year, we combined the continuation of well-established education and outreach programmes with the start of new lines of activity, namely those concerning collaborations with schools along the year on more hands-on projects. In 2020, we expect this scenario to evolve in the following way:

(i) on the continuity side, the main activities will be IPPOG's International Masterclasses, CERN's Portuguese Language Teachers Programme, seminars in schools and public sessions at LIP and elsewhere. The external goal is to maintain or increase the levels of participation of the public (schools and general publics). In what concerns seminars and public sessions, an effort will be made to improve the reach in regions of the country usually less covered by such activities, using both the geographic spread of LIP and also webcast means. Internal goals are to widen the participation of the LIP community (namely the scientific groups and the graduate students) and achieve a better coordination and communication between the activities developed at the different LIP nodes.

(ii)we expect to consolidate the projects with schools along the year and hands-on activities. Profiting from the partnerships established in 2019 with several science clubs in schools, it is now time to intensify the participation in the activities of these clubs. Sharing of know-how and equipment between the different nodes is the right way to go. In what concerns specifically the LIP-EduLab, it will continue be developed under the motto "particle physics and its tools" and, as stated above, the plan for the near future is to concentrate on the development of the laboratory itself, equipping it with new material and projects. Contacts with students will happen through visits to LIP (talk + cloud chamber building workshop) and through the support to projects under development in the schools by the involved teachers. Clearly, much will depend on the available resources during the next few years. LIP-ECO will also give support to the outreach component of LIP's muon tomography project MuTom. Our plans include the development of a module for the local science exhibition, of posters for the visitor centre and for the detector location, and the continuation and development of in situ talks, visits, workshops and demonstrations.

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 highly valuable asset to engage schools in our activities, taking advantage also of their distribution in 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 the current and mandatory tasks, there is little time left to expand our activities or to implement new ideias.

Opportunities: The support of the LIP management and of a good fraction of the LIP community. The many suggestions received from LIP members, and the will to participate shown by several graduate students and young researchers. The possibility to offer internships (3 months) to science communication students.

Threats: The lack of prospects of an 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 time taken to prepare new projects and experiments, that calls for a great resilience on the prospective future scientists, can hinder the engagement of the young and diminish their enthusiasm to follow a career in STEM.

Note: Several of the events foreseen for the first semester of 2020 had to be canceled or postponed due to the COVID-19 crisis.

Summary Tables

Funding

Human Resources

Scientific Output

Summary Tables...

FUNDING

Group	Code	Amount	Dates	LIP node
ATLAS	IF/01586/2014/CP1248/CT0003	42.000 €	2015-01-01 / 2019-12-31	L/C/M
"	CERN/FIS-PAR/0008/2017	313.000 €	2017-07-01 / 2019-08-31	"
"	CERN/FIS-PAR/0033/2019	191.250 €	2019-09-01 / 2021-08-31	"
"	CERN/FIS-PAR/0002/2019	180.000 €	2019-09-01 / 2021-08-31	"
CMS	IF/00772/2014/CP1248/CT0002	50.000 €	2015-01-01 / 2019-12-31	L
"	AMVA4NewPhysics - 675440	238.356 €	2015-09-01 / 2019-08-31	"
"	CERN/FIS-PAR/0006/2017	345.000 €	2017-08-01 / 2019-07-31	"
"	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/0034/2017	10.000 €	2018-01-01 / 2019-12-31	"
"	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 €	2020-03-01 / 2022-02-28	"
"	CERN/FIS-PAR/0010/2019	20.000 €	2020-09-01 / 2022-08-31	"
Partons and QCD	CERN/FIS-PAR/0007/2017	144.500 €	2017-09-01 / 2019-08-31	L
"	CERN/FIS-PAR/0022/2019	155.000 €	2019-09-01 / 2021-08-31	"
NUC-RIA	CERN/FIS-PAR/0005/2017	24.640 €	2018-07-01 / 2020-06-30	L
AMS	CERN/FIS-PAR/0020/2017	35.000 €	2017-09-01 / 2019-08-31	L
"	CERN/FIS-PAR/0013/2019	50.000 €	2019-09-01 / 2021-08-31	"
Auger	IF/00820/2014/CP1248/CT0001	50.000 €	2015-01-01 / 2019-12-31	L/C/M
"	CERN/FIS-PAR/0023/2017	150.000 €	2017-05-02 / 2019-08-31	"
"	CERN/FIS-PAR/0034/2019	135.000 €	2019-09-01 / 2021-08-31	"
"	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
Dark Matter	IF/00877/2015/CP1311/CT0002	50.000 €	2016-11-01 / 2021-11-30	C

Group	Code	Amount	Dates	LIP node
Dark Matter	PTDC/FIS-PAR/28567/2017	239.807 €	2018-09-01 / 2021-08-31	C
Neutrino	IF/00248/2015/CP1311/CT0001	50.000 €	2017-01-01 / 2021-12-31	L
"	CERN/FIS-PAR/0012/2019	130.000 €	2019-09-01 / 2021-08-31	"
SHiP	CERN/FIS-PAR/0030/2017	10.000 €	2018-01-01 / 2019-12-31	L/C
RPC R&D	AIDA-2020	45.000 €	2015-06-01 / 2019-05-31	C
"	STRATOS R&D	20.000 €	2019-01-01 / 2020-12-31	"
"	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 €	2020-01-01 / 2021-12-31	"
Neutron Detectors	654000 SINE2020	161.913 €	2015-10-01 / 2019-09-30	C
Gaseous Detectors R&D	CERN/FIS-INS/0025/2017 - GD	35.000 €	2018-05-01 / 2020-04-30	C
Liquid Xenon R&D	CERN/FIS-INS/0025/2017 - LXe	35.000 €	2018-05-01 / 2020-04-30	C
"	CERN/FIS-INS/0026/2019	35.000 €	2020-11-01 / 2022-10-31	"
OR Imaging	CERN/FIS-INS/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
"	ESA/4000115004/15/NL/RA/ZK	80.116 €	2015-11-13 / 2019-12-31	"
i-Astro	654215 - AHEAD	61.225 €	2015-09-02 / 2024-03-01	C
"	871158-AHEAD 2020	30.000 €	2020-03-02 / 2024-03-01	"
GRID	INCD 01/SAICT/2016 - nº 022153	223.000 €	2017-07-18 / 2020-07-17	L
"	DEEP-HybridDataCloud - Grant 777435	362.500 €	2017-11-01 / 2020-04-30	"
"	EOSC-hub grant 777536	338.687 €	2018-01-01 / 2020-12-31	"
"	EOSC-synergy grant 857647	433.000 €	2019-09-01 / 2022-02-28	"
"	BigHPC 04/SI/2019	249.592 €	2020-03-01 / 2023-02-28	"
Simulation & Big Data	PTDC/FIS-PAR/29147/2017, POCI/01-0145-FEDER-029147	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
"	92-2018/841 Masterclasses	2.500 €	2019-02-15 / 2019-08-31	"

Human Resources on research

Group	FTE	Persons(*)	Researchers	Technicians	PhD	Master	Undergrad	External
ATLAS	18.9	32	14	4	8	6	1	12
CMS	12.9	18	9	2	4	3		14
Pheno	12.4	22	11		4	7	1	7
Partons and QCD	4.5	7	6	1			1	
HADES	0.5	5	3	2				
NUC-RIA	5.4	6	1		3	2		2
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AMS	3.3	5	4		1			2
Auger	11.4	22	16	4	2		1	3
LATTES	4.1	17	11	4	1	1		6
Dark Matter	11.8	19	9	2	2	6		
Neutrino	6.5	13	9		3	1		1
SHiP	3.2	13	6	6		1	2	
RPC R&D	4.1	14	5	7	1	1		
Neutron Detectors	1.3	4	4					1
Gaseous Detectors R&D	4.2	8	6		1	1		1
Liquid Xenon R&D	1.1	4	4					
OR Imaging	2.0	3	3					
Gamma Cameras	2.2	8	5	2	1			1
Dosimetry	4.7	9	3		2	4		1

Human Resources on research

Group	FTE	Persons(*)	Researchers	Technicians	PhD	Master	Undergrad	External
Space Rad	6.7	11	7		1	3		1
i-Astro	3.5	10	7		2	1	2	1
GRID	11.2	12	5	7				5
Advanced Computing	3.0	4	1			3		3
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Radiation, health and environment	5.6	9	5		3	1		2
TOTAL	160	203	92	28	34	39	8	71

(*) Please note that the total of the Persons column is not the sum of the column, as one person often participates in several groups.

Scientific output

Group	Papers w/ Direct Contribution	Papers in Referred journals	Books, Reports and Proposals	Notes	Oral Presentations in Int. Conf.	Poster Presentations in Int. Conf.	Other Presentations	Proceedings	PhD Theses	Master Theses	Events
ATLAS	3	91	5	11	8	2	53	6	1	2	
CMS	5	131	3	11	6		40	3		2	
Pheno	15	15	3		10		6	7		3	
Partons and QCD	2	3			2		3	1			2
HADES	1	9									
NUC-RIA	1	2							1		
AMS	1	4			1		4				
Auger	3	7		3	7	1	29	9			
LATTES	1	1			2	1	4	1		1	
Dark Matter	3	5		4			8				
Neutrino	3	6		3		1	8	3		1	
SHiP		2									
RPC R&D	2	2			2	2	1	3		1	
Neutron Detectors	3	3					2				
Gaseous Detectors R&D	2	7									
Liquid Xenon R&D											
OR Imaging						1					
Gamma Cameras											

Scientific output

Group	Papers w/ Direct Contribution	Papers in Referred journals	Books, Reports and Proposals	Notes	Oral Presentations in Int. Conf.	Poster Presentations in Int. Conf.	Other Presentations	Proceedings	PhD Theses	Master Theses	Events
Dosimetry					1	1		2		3	
Space Rad	3	3			4	2	19		1	2	
i-Astro	3	3	2	1	5	5	15	2	1		3
GRID	1	1		12	11	1	8	3			1
Advanced Computing										1	
LOMaC				1							
TagusLIP laboratory		1									
Simulation & Big Data	4	4			3		9			4	2
Radiation, health and environment				2	9		5	6		1	
Total	**54**	**297**	**9**	**47**	**68**	**17**	**208**	**46**	**4**	**18**	**8**

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

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