LIP DETAILED 2018 REPORT

and plan for 2019

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

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Foreword

Mário Pimenta
President

The quest to understand the Universe we live in is nowadays pursued in the framework of large international collaborations all around the World. It is a fantastic scientific and technological endeavour involving many tens of thousands of students, researchers, engineers and technicians. How can an institution with limited resources engage, with success and impact, in such an enormous enterprise? The key for LIP has been, since its very beginning, the quality and enthusiasm of its members, allied with clear medium- and long-term strategic planning, which must be continuously followed and periodically reviewed.

We are now in the middle of such an exercise involving, for the first time, LIP's scientific council as a whole. It is also a time when this debate is carried out at the European and World level, namely in the framework of the revision led by CERN of the European Strategy for Particle Physics, and of the European Astroparticle Physics Strategy elaborated by the Astroparticle Physics European Consortium (APPEC).

So, where do we stand?

In **Physics with accelerators** our first priority for the next five/ten years is the participation in the CERN LHC upgrade program, leading to an increase of the present luminosity by an order of magnitude, allowing therefore to test the Standard Model with an unprecedented accuracy and to study incredibly rare (or forbidden!) channels. There, both in the ATLAS and the CMS experiments, our engagement is already well established, with clear priorities in physics channels and in the upgrade of the detectors, including a large involvement of the Portuguese industry. On the other hand, several lines of phenomenological work that were carried out at LIP in the past are now consolidated into a single and very active scientific group, bridging theory and experimental work and boosting our activities in these domains.

In the longer term we favour the option for the Future Circular Collider (FCC) at CERN, which would explore a new energy frontier and would maintain the European leadership in Particle Physics for many, many years. In the fixed target program, we are now participating in two proposals, both for CERN-based experiments: a new QCD program and a high intensity beam dump experiment, which would allow the abundant production of neutrinos of all the families and would explore a possible "New Physics" hidden sector, the SHiP experiment. CERN will take a decision on the fixed target program for the next decade somewhere towards the end of 2020 and we will proceed accordingly.

In **Cosmic rays physics** our focus has been on the study of charged cosmic rays, both at low energies (AMS) and at ultra-high energies (Pierre Auger Observatory). These experiments will continue taking data in the next five years and progress may be reached, for instance, in the clarification of whether a 1 TeV Dark Matter particle would be in the origin of the unexpected positron and anti-proton spectrum observed by AMS experiment. Also on whether the "composition puzzle" observed by the Pierre Auger collaboration is originated by an unexpected composition spectrum at the high energy astrophysics sources or by an unexpected behaviour of the hadronic interactions at energies well above those available in the LHC. An engineering array of 40 MARTA RPC detectors developed by LIP will be soon installed in the Pierre Auger site and will contribute to a better understanding of the muon content of extended air showers. The muon RPC telescopes developed in this context are also now in the heart of an exploratory project to characterize geological structures. A proof of concept is now being carried out at the "Mina do Lousal – Centro Ciência Viva" in collaboration with colleagues from the University of Évora and the Faculty of Sciences of the University of Lisbon.

On the other hand, in the last years we started a new project aiming at the construction of a wide field gamma ray observatory at high altitude in the South Hemisphere. The large majority of the international community interested in this field will meet next May in Lisbon. A three-year R&D project, supported by institutions from Portugal, Brazil, Italy, Germany, USA, Spain and Czech Republic, to define the physics goals, the design and the location of such observatory, will start soon.

In **Underground experiments**, the SNO+ neutrino experiment and LZ dark matter experiment will both undertake ambitious physics programs within the next five years. The proof of the existence of neutrinoless double beta decay or of a WIMP dark matter particle may be within the reach of these experiments. The expertise that LIP groups have acquired, namely in the detailed understanding of the detector response, backgrounds and analysis methods, as well as in the development of calibration and detector control systems, is a solid base for our near future directions.

These two LIP "Underground" groups are now jointly entering the Deep Underground Neutrino Experiment (DUNE), a long baseline neutrino facility supported by a joint venture of FERMILAB and CERN, aiming for a high precision study of neutrino oscillations, which will allow to explore CP violation and the mass hierarchy in the neutrino sector.

In **Low Energy Hadronic Physics** GSI/FAIR will be the central European facility for the study of nuclear reactions and nuclear structure for the next decade, and ISOLDE at CERN will be the main European laboratory for producing and investigating radioactive isotopes. The two LIP groups that have been participating in these facilities, with limited but targeted and recognized activities, have different backgrounds and tradition but have now established a close cooperation. They are together leading the experimental nuclear physics activities in Portugal. The political decision on the level of the Portuguese participation at FAIR will be a determinant factor for the medium-term strategic planning of these activities at LIP.

Detector R&D is part of LIP's DNA, and in particular in Coimbra which has a long and well recognized tradition in radiation detection technologies, namely in Resistive Plate Chambers (RPC). In the recent past it was not often possible to obtain the appropriate level of funding for several of these activities. Exploratory and innovative projects are a must, but they have to have a clear time framework and the necessary resources. Priorities have thus, in each moment, to be established.

In this line, there was recently a reinforcement of the human resources allocated to the teams committed to the development of RPC detectors in three different applications: high position and time resolution trackers; low flux, autonomous and environmentally robust detectors; and 3He-free Position Sensitive Neutron Detectors.

Particle Physics technologies have a direct application in the development of detectors and methods in the Health and Space fields. Here again, and fortunately, there are many ideas and possible projects, and choices have to be made.

In **Health applications**, LIP has, in collaboration with ICNAS and CTN/IST, established a clear priority in the development of detectors and methods for proton therapy, and in imaging RPC-PET detectors. In proton therapy, the focus will be in the development of orthogonal computed tomography systems (OrthoCT) and in dosimeters of high-resolution and/or of micrometer-size. These projects will, whenever possible, benefit from collaborations with international reference institutes. In RPC-PET imaging, the project to develop a high-resolution brain scanner was recently approved and a full prototype will be built during the next three years. During the same period the existing prototype of the small animal PET will be updated to cover a wider solid angle.

In **Space applications**, LIP has recognized competences in the study of space radiation and its effects, in the design and simulation of radiation detectors, and in x- and gamma-ray polarimetry. We are now members of instrument consortia or scientific teams that have proposed to ESA planetary and astrophysics missions which will be evaluated in the next months. With the recent creation of the Portuguese Space Agency, we are confident that support for the Portuguese participation in space missions will clearly increase, boosting as well the collaboration that we have been developing with Portuguese industry and with schools and science outreach centers.

The needs in **Computing** are always exponentially growing. In fact, just as an example, the High Luminosity LHC will demand, by 2025, a total computing capacity 50-100 times greater than today, and data storage of the order of exabytes. In Portugal, in terms of resources, it has not been possible to cope with such a large growth in the recent past. Nevertheless, clear progress was made, with the creation of the Portuguese National Distributed Computing Infrastructure (INCD) in a partnership between FCT, LIP and LNEC. INCD provides support for human resources and computing services, through FCT infrastructures roadmap funding. This funding will have to be renewed in 2021. However, the LIP internal information technology (IT) services are not funded by INCD and an alternative source of funding must be found.

Apart from coordinating the INCD development and operational activities, the LIP computing group supports all the LIP IT services and have been, and will be, deeply involved in international service and research projects, both at Iberian and European level.

The LIP **Scientific Infrastructures** were created mainly to support the experimental activity of LIP's research groups, being able to provide a diversified set of services: from the design, production and testing of mechanical structures to the development and production of large area radiation detectors; from the design of complex electronic circuit boards to testing scintillators and WLS fibres. Their contribution has been essential in many research and outreach projects and they were also able to provide selected services to external clients. However, their resources are limited and the capability of an adequate planning of their work was not always possible. Their installations were enlarged and improved recently, both in Lisbon and Coimbra and, hopefully, will be fully ready during the current year.

The way forward is clearly: the reinforcement of the scientific infrastructures own management and planning; the increase of their funding, exploiting namely possible re-equipment programs and opportunities for high valued external work; and the reinforcement, whenever needed, of their human resources.

The **LIP Competence Centers**, joining all LIP members sharing common technical expertise and tools, were created to increase synergies between LIP groups and to boost our collaboration with University and Industry. In the last two years, two Competence Centers were formed, one in “Simulation and Big Data” and the other in “Monitoring and Control”. They are already quite active internally, and externally first steps were taken. One example is the organization of two editions of the open school and symposium “Data Science in (Astro)Particle Physics: The Bridge to Industry”, held in 2018 in Lisbon and in 2019 in Braga with a large participation of the Portuguese industry.

In the next few years the Competence Centers should consolidate their activities, increasing in particular their interaction with the outside world.

Education, outreach and advanced training are an integral part of LIP’s mission. An intense activity has been carried out and landmark examples are, for instance, the “International Masterclasses in Particle Physics” events, involving more than one thousand high school students all over Portugal, from Ponta Delgada to Bragança; the “Portuguese Language Teeacher’s Programme” organized every year at CERN, which have already involved hundreds of teachers from all the Portuguese speaking countries; the LIP Summer Internships Programme for university students, which has involved last year over 60 students in Lisbon, Coimbra and Braga; the coordination of national and international PhD network programs which hold annual international schools and workshops.

The path followed so far will be pursued, and new challenges will also be explored, such as dedicated partnerships with high schools, to develop for selected classes a coherent set of activities throughout the academic year.

The backbone of any institution are its human resources, namely, in our case, our **researchers, engineers and technicians**. We are not yet in a stable situation in what concerns employment. Long term post doc grants are over. Nowadays, at LIP, every researcher who has held a PhD for more than three years has a contract. However, the number of permanent positions, either at LIP and/or in the university is not at all sufficient, and the career path for the LIP staff members is not well defined. Our goal is, in five years, to have more than 100 researchers of which 2/3 have permanent positions (half in the university and half at LIP) and 1/3 with fixed-term positions, including a few recent post-docs. The regular evaluation of all the LIP staff members is mandatory and will start already this year. Such evaluation cycles will be a tool to improve the working conditions including, if mutually agreed upon, through advanced training opportunities, and to support career progression decisions.

LIP celebrates this year, on May 9th, its 33rd year anniversary, and it is the major Institution of particle and astroparticle physics in Portugal. Thus, we have a special responsibility not only in the future of this domain in Portugal but also in contributing to make better the society we will all live in.

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**

Computing

[LHC experiments and phenomenology]

ATLAS
CMS
Pheno

ATLAS

Collaboration in the ATLAS experiment at CERN

Principal Investigator:
Patricia Conde (85)

17 *Researcher(s):*
Agostinho Gomes (85), Amélia Maio (30), António Onofre (15), António Pina (25), Bruno Galhardo (100), Filipe Veloso (80), Helena Santos (85), Helmut Wolters (70), João Gentil (85), Juan P. Araque (20), Liliana Apolinário (15), Marcin Stolarski (20), Miguel Fiolhais (30), Nuno Castro (40), Ricardo Gonçalo (50), Rui Faísca Pereira (88), Rute Pedro (100)

3 *Technician(s):*
Filipe Martins (100), Luís Gurriana (75), Luís Seabra (100)

7 *PhD Student(s):*
Ademar Delgado (10), Ana Peixoto (70), André Pereira (50), Emanuel Gouveia (100), Maria Ramos (10), Susana Santos (75), Tiago Vale (70)

11 *Master Student(s):*
Aidan Kelly (75), Ana Carvalho (100), André Reigoto (37), António Costa (83), Christopher Pease (20), David Fernandes (69), Maura Teixeira (50), Pedro Lagarelhos (50), Ricardo Barrué (50), Ricardo Faria (25), Rui Martins (36)

8 *Trainee(s):*
Alexandre Santos, Carlos Vítor, Eduardo Ferreira, Filipe Barroso, Francisco Lelewell, Joshua Winter, João Bravo, Vânia Nunes

7 *External collaborator(s):*
André Wemans, Artur Amorim de Sousa, Gianpaolo Benincasa, Guiomar Evans, José Rufino, José Soares Augusto, Juan Antonio Aguilar Saavedra

Total FTE:
22.8

Article(s) in international journals:
11 Direct contribution
103 Indirect contribution
Internal note(s):
8 Collaboration note(s)
Proposal(s):
3
International conference(s):
6 Oral presentation(s)
4 Poster(s)
5 Proceeding(s)
International meeting(s):
4 Oral presentation(s)
National conference(s):
8 Oral presentation(s)
11 Poster(s)
Collaboration meeting(s):
177 Oral presentation(s)
Seminar(s):
10 Seminar(s)
18 Outreach seminar(s)
Completed theses:
4 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 to 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 was in production mode, running steadily and delivering a total integrated luminosity of 70 fb^{-1}. The efforts of the collaboration went into ensuring a stable detector operation and data taking, resulting in around 97.5% efficiency for physics quality data. In parallel, the detector upgrade developments continued in full swing with the preparation for the Technical Design Reports of the Phase II Upgrade and the continuation of the Phase I projects.

Sources of funding

Code	Amount	Dates	Description
IF/00955/2013/CP1172/CT0004	50.000 €	2013-12-01 / 2018-11-30	Expl. 2014 PM - IF/00050/2013/CP1172/CT0004
IF/00050/2013/CP1172/CT0002	50.000 €	2014-01-01 / 2018-08-31	Expl. 2014 NC - IF/00050/2013/CP1172/CT0002
IF/01586/2014/CP1248/CT0003	42.000 €	2015-01-01 / 2019-12-31	Expl. 2015 HS - IF/01586/2014/CP1248/CT0003
CERN/FIS-PAR/0008/2017	340.000 €	2017-07-01 / 2019-06-30	Collaboration in the ATLAS experiment

Total: 482.000 €

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). We are currently focused on the study of the Vts vertex through the measurement of the top decays to Ws and on the search for new physics phenomena above the TEV scale using top quark precision measurements such as W and top polarization in the context of an effective field theory approach.
- 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.
- 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. For Run 2 we are concentrated on the study of heavy flavour jets production.

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

- TileCal (A. Gomes). We are leading the development, maintenance and continuous upgrade of the DCS system, contributing to the calibration and to ageing studies of the scintillators and WLS fibres.
- Jet Trigger (R. Gonçalo). We have long expertise in jet reconstruction, hadronic calibration and real time algorithms. We contribute to the jet trigger operations and monitoring.
- Forward Detectors (P. Conde, N. Castro). We have leading positions in the maintenance and continous upgrade DCS of the ALFA and AFP detectors. In ALFA we are fully responsible for the DCS 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 are responsible for replacing gap/crack 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.
- Jets high level trigger system (P. Conde, R. Gonçalo). Our focus is on the development of parallel real time algorithms that use General Purpose Graphical Processing Units (GPU) as hardware accelerators. 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.

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:

- Finish the study of the ATLAS sensitivity to anomalous CP components in the H→bbgamma vertex.
- Contribute to the searches for the SM H → bb in the VH and ttH production channels.
- Study the feasibility of a bump-hunting type search for ttH(bb) at the HL-LHC.

Top quark properties:

- Continue the study of the Vts vertex with the full 13 TeV dataset.
- Lead and actively contribute to the effective field theory interpretation of precision measurements in the top quark sector.

Exotic searches:

- Continue the t→qZ decay and tZ production FCNC searches with the full 13 TeV.

Publish the two following searches using the 2015+2016 datasets and prepare the upgrade of the analysis of the full run-2 dataset on those channels:

- Search for vector-like quarks in the Zt/b+X channel.
- Search for events with a top quark and missing energy.

Continue the contribution to the combination of all the ATLAS analyses sensitive to the pair production of vector-like quarks. Contribute to the general strategy of the Exotics Group in terms of searches for alternative production and decay mechanisms of vector-like quarks and the search for dark matter in the top quark sector using the full run-2 dataset data and beyond.

Heavy Ion physics:

- Focus on the study of heavy flavour jet production, benefiting from the b-tagging techniques developed in our group.
- Contribute to the preparation of the b-jet trigger menu in Pb+Pb data acquisition in the Fall 2018.

Detector maintenance, operation and upgrade

Forward Detectors:

- AFP trigger:
    - 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:

- 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.

With respect to the TileCal DCS, the objectives for 2018 are:

- Maintain reliability of the DCS during operations and improve functionality when needed.
- Finish migration of the DCS software for the new operating system and new WinCC version.
- Develop, test and implement a DCS component for the Cesium Calibration System.
- Improve the DCS system for the Upgrade HVRemote boards and the monitoring of temperatures and voltages of the upgrade electronics.

In what corresponds to the TileCal upgrade:

- Develop a test bench for the quality control of the high voltage regulation systems of the upgrade of the TileCal.
- Test the first HVRemote board in Lisbon and in test beams at CERN.
- Design a crate to house the HVRemote boards and the primary HV boards.
- Finish the re-design and production the prototype 2 of HVRemote, with 48 channels per board.
- Test the new cable prototypes and connectors to ensure qualification of the cabling system.
- Aluminization of WLS fibres for the scintillators replacement and addition of E4' new scintillators.
- Irradiation and tests of scintillators and fibres at CTN (Lisbon).

Jet trigger:

- Write internal ATLAS note documenting our proposed method to correct the jet rate increase due to ageing of the crack scintillators.
- With respect to the upgrade, study new possibilities to further improve the performance of the GPU calorimeter trigger prototype and reduce the data transfer overheads.

Our group is also responsible for the jet data quality monitoring during the Heavy Ion data acquisition and is committed with studies on jet quality, jet constituents and validation of underlying event subtraction.

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.

Achievements and responsibilities during the past year

Awards

- A. Peixoto was awarded one of the three prestigious ATLAS PhD grants attributed to young, outstanding students.

Physics

Higgs:

- Contributed to the first observation, published by the ATLAS collaboration, of:
    - Higgs decaying to b-quark pairs and VH production, with responsibility on the global fits.
    - ttH associated production, with data-driven background studies for the di-leptonic final state, with H→bb.

- Finished two sensitivity studies that are currently being prepared for publication:
    - Study of anomalous CP components in the H→bby vertex.
    - Bump-hunting type search for ttH(bb) at the HL-LHC.
- Started the preparation of the measurement of the high transverse momentum production cross section of H→bb in VH associated production, with a study of optimal boosted tagger options for this search and the preparation of the fitting tools.
- The Xbb tagger framework, used to tag boosted resonance decays to b-quark pairs, was updated to the newest ATLAS release, and the analysis-level performance corrections produced.

Top quark precision measurements:

- Continued the study of the Vts vertex through the measurement of the top decays to Ws.
- Leading role in the effective field theory interpretation of the ATLAS top quark analysis, 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:

- Contributed to the Yellow Report, submitted to the European Strategy Group, with the study of the sensitivity to FCNC decays t->qZ using the upgraded ATLAS experiment at the High Luminosity LHC scenario.
- Three analysis led by our group and using the 2015+2016 data set were finished:
    - Search for vector-like quarks in the Zt/b+X channel (published in PRC).
    - Search for the production of top quarks accompanied by missing transverse energy (submitted to JHEP).
    - Search for t→qZ FCNC decays (published in JHEP).
- The search for tZ production via FCNC in top pair production at 13 TeV with 2015 and 2016 datasets was approved by the top working group.
- Contribution to the first efforts of combination of the ATLAS searches for vector-like quarks (published as editor's suggestion in PRL).
- Contribution, with the monotop channel, to the global combination of the ATLAS searches for dark matter (paper in preparation).

Heavy Ions:

- Developed b-tagging techniques for Heavy Ion collisions and integrated them for the first time in the ATLAS reconstruction software for the Heavy Ions run.
- Prepared the b-jets trigger menu for the Pb+Pb run and realised b-jet trigger performance studies.
- Improved the jet monitoring infrastructure for the Pb+Pb run.
- Validation studies on data acquired during the Pb+Pb run.
- Prepared Monte Carlo simulation of b-jets produced in Pb+Pb collisions.

Detector-related activities

We contributed to detector operation and data quality control with on-call and data quality shifts in all detector areas were we participate.

TileCal detector maintenance, operation and upgrade:

DCS:

- Updated and maintained the DCS software and hardware for the TileCal and the demonstrator test beam.
- Assistance for detector maintenance teams during shutdowns.
- Development of new user interfaces to ease the tasks of the on-call shifter during data taking.
- Implementation of a procedure to automatically power-cycle the front-end boards when an increase of current is detect.

TileCal calibration:

- Contributed to the Optics Robustness task force, studying the light loss of scintillators and fibres due to radiation damage using data from the calibration systems and pp collisions. Preliminary results indicate 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.
- Assumed the responsibility of documenting the activities and results of the laser calibration during the LHC run-2 in an internal note, which is ongoing.

Upgrade activities:

- Aluminization of the top end in 2500 WLS optical fibers for the instrumentation of the TileCal gap counters for the Phase I Upgrade done at LOMaC. A light yield dispersion of <3.2% and an average mirror reflectivity coefficient of 82% were measured for the aluminized fibers.
- Tested the first prototype of HV distribution board (HVRemote) for the Phase II Upgrade in the laboratory at FCUL. Problems on some components were identified and corrected in the second prototype, delivered to CERN for further tests in the lab.

- The design of a third prototype with double number of channels per board is ongoing, incorporating all the improvements identified so far.
- Tested at CERN the first HV distribution cable with reduced profile produced by the Portuguese company Cabelte.
- Defined and reviewed the schedules and foreseen cost of the system in preparation for the TileCal Phase II TDR.

Forward Detectors:

- Software migration, maintenance and development of the ALFA and AFP DCS.
- Maintenance and development of the ALFA DCS.
- Supported the operations of the AFP detector with expert-on-call shifts at CERN.

Jet trigger maintenance, operation and upgrade:

- Wrote internal ATLAS note documenting our proposed method to to improve the jets energy measurement in the TileCal gap/crack.
- Started to study of a benchmark process for the HTT: boosted di-Higgs production in the 4b final state.
- Supported the ATLAS trigger operation as jet, calorimeter and missing energy experts and in online software validation

Distributed computing

- Excellent operation of the 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 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) and in FCUL/IST in July.
- Contributed to the organization, lectures and hosted 12 students in the LIP summer students internship in Lisbon, Coimbra and Minho.

Responsibility positions within the ATLAS Collaboration (in 2018)

- 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, theory hot-spot contact for the vector-like quark searches within the Exotics Working Group (2014-2018).
- N. Castro, contact person for the effective field theory interpretations of the Top Quark Working Group (since September 2017).
- J. P. Araque, contact editor for the search for vector-like quarks in the Zt/b+X channel (till March 2018).
- N. Castro, contact editor for the search for monotop events plus missing energy.
- N. Castro, analysis contact for the search for tZ production via FCNC.
- N. Castro, J.P. Araque, members of the ATLAS Physics Office.
- F. Martins, TileCal DCS coordinator.
- L. Seabra, AFP DCS co-cordinator, ALFA DCS responsible.
- P. Conde, member of the Panel for Operation Task Sharing.
- F. Veloso, contact editor for the search for the $t \to qZ$ decay.
- R. Pedro, TileCal Calibration co-coordinator.

Editorial Boards

Members of our group participated in 9 ATLAS Editorial Boards: H. Santos (2, one as chair), N. Castro (2, 1 as chair), F. Veloso (1), A. Onofre (1), P. Conde (2), J. P. Araque (1, as chair).

Lines of work and objectives for next year

Physics studies

Higgs physics:

- Contribute to the measurement of the high pT cross section of the $H \to bb$ decay in VH production, with responsibility on the fits an the 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 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 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 ongoing effort in the use of state-of-the art techniques for data analysis will be continued and possible synergies with the LIP Competence Center on Simulation and Big Data will be explored. 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, in particular 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. 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.

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 analysis. The group has experimental labs in Lisbon (LOMaC), dedicated to calorimetry and instrumentation for processing and characterization of optical wave length shifting and scintillating fibres, plastic scintillators and photomultipliers. There is also expertise on electronics and advanced computing.

In the area of physics analysis we have made important contributions to the Higgs discovery and physics 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.

Weaknesses

The group has still few PhD students in Lisbon and Coimbra. Our efforts in outreach in the universities and the summer internship attracted new master students but we need to ensure their continuation for PhD and maintain the rate of new master students.

The lack of sufficient funding and the reduced number of FCT postdoctoral grants/contracts resulted in the loss of two postdocs, with a considerable reduction in person-power in specific areas.

Opportunities

We are a national team with connections to many of the universities in the country. The new appointments as professors two members of the group (one at IST and another at Minho University), place us in an optimal situation to strengthen our connection to the universities and attract new 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.

Threats

The funding structure in Portugal continues to be unstable and poorly adjusted to large continuing projects. The reduction of funding in the last call and the lack of other sources of funding forced to a reduction of the human-power effort in terms of postdocs, that is critical in some areas of the group.

Many key members of the group continue in an unstable contractual situation, that can become critical in the near future.

ATLAS

Publications

11 Articles in international journals

(with direct contribution from the team)

- *"Search for the standard model Higgs boson produced in association with top quarks and decaying into a b(b)overbar pair in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, Phys. Rev. D 97 (2018) 072016
- *"Search for flavour-changing neutral current top-quark decays t -> qZ in proton-proton collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, J. High Energy Phys. 7 (2018) 176
- *"The High Voltage distribution system of the ATLAS Tile Calorimeter and its performance during data taking"*, D. Calvet, S. Calvet, R. Chadelas, D. Cinca, Ph. Grenier, P. Gris, P. Lafarguette, D. Lambert, M. Marjanovi, L. F. Oleiro Seabra, F. M. Pedro Martins, J. B. Pena Madeira Gouveia De Campos, S. M. Romano Saez, P. Rosnet, C. Santoni, L. Valéry, F. Vazeille, JINST 13 (2018) P08006
- *"Search for pair production of heavy vector-like quarks decaying into high-(PT) W bosons and top quarks in the lepton-plus-jets final state in pp collisions at root s=13 TeV with the ATLAS detector"*, ATLAS Collaboration, J. High Energy Phys. 8 (2018) 048
- *"CP tests of Higgs couplings in tth semileptonic events at the LHC"*, D. Azevedo, A. Onofre, F. Filthaut, and R. Gonçalo, Phys.Rev. D98 (2018) 033004
- *"Observation of Higgs boson production in association with a top quark pair at the LHC with the ATLAS detector"*, ATLAS Collaboration, Phys. Lett. B 784 (2018) 173, arXiv:1806.00425 [hep-ex]
- *"Observation of H -> b(b)over-bar decays and V H production with the ATLAS detector"*, ATLAS Collaboration, Phys. Lett. B 786 (2018) 59-86
- *"Search for charged Higgs bosons decaying into top and bottom quarks at $sqrt{s}$ = 13 TeV with the ATLAS detector"*, ATLAS collaboration, JHEP 1811 (2018) 085
- *"Combination of the Searches for Pair-Produced Vectorlike Partners of the Third-Generation Quarks at root s=13 TeV with the ATLAS Detector"*, ATLAS Collaboration, Phys. Rev. Lett. 121 (2018) 211801
- *"Operation and performance of the ATLAS Tile Calorimeter in Run 1"*, ATLAS collaboration, Eur.Phys.J. C78 (2018) 987
- *"Search for pair and single production of vectorlike quarks in final states with at least one Z boson decaying into a pair of electrons or muons in pp collision data collected with the ATLAS detector at root s=13 TeV"*, ATLAS Collaboration, Phys. Rev. D 98 (2018) 112010

5 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, ATL-PHYSPROC-2018-109, in Proceedings of BEACH 2018 – XIII International Conference on Beauty, 17 – 24 June
- *"Control System For ATLAS TileCal HVRemote Boards"*, F. Martins, L. Gurriana, L. Seabra, G. Evans, A. Gomes, A. Maio, C. Rato , J. Sabino, J. Soares Augusto, C17-10-08 (2018) THPHA069
- *"Jets in heavy ion collisions with the ATLAS detector"*, H.Santos, ATL-PHYS-PROC-2018-001
- *"Probing the CP nature of the Higgs coupling in tth events at the LHC"*, Emanuel Gouveia, S. P. Amor dos Santos, M. C. N. Fiolhais, R. Frederix, R. Gonçalo, R. Martins, A. Onofre, C. M. Pease, H. Peixoto, A. Reigoto, R. Santos, J. Silva, arXiv:1801.04954
- *"Optics robustness of the ATLAS Tile Calorimeter"*, R. Pedro, ATL-TILECAL-PROC-2018-010

3 Proposals

- *"Future Circular Collider - Vol. 3: The Hadron Collider (FCC-hh)"*, A. Abada, R. Gonçalo, J.G. Mendes Saraiva et al, CERN-ACC-2018-0058, FCC Conceptual Design Report (submitted to Eur. Phys. J.)
- *"Standard Model Physics at the HL-LHC and HE-LHC"*, Azzi Patrizia and others, CERN-LPCC-2018-03
- *"Higgs Physics at the HL-LHC and HE-LHC"*, M. Bengala, A.J. Costa, M. Gallinaro, R. Gonçalo, E. Gouveia, P.C. Muiño, R Santo, and G. Strong, et al., CERN-LPCC-2018-04

5 Internal notes

- *"Correction of Trigger Jets Using Gap and Crack 2 Tile Calorimeter Scintillators"*, Emanuel Gouveia, Ricardo Gonçalo, António Onofre, ATL-DAQ-INT-2018-001
- *"Supporting note for the Tile Calorimeter Run-1 paper"*, ATLAS TileCal Group, ATL-COM-TILECAL-2018-004
- *"Measurement of the t bartV (V=WZ) cross-sections in proton-proton collisions at sqrts=13 TeV with the ATLAS detector"*, Bessidskaia Olga and others, ATL-COM-PHYS-2018-425
- *"Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a pair of b-quarks"*, ATLAS VHbb Higgs Subgroup,
- *"Simplified Template Cross-Section measurements for the VH(H->bb)VH(H->bb) process with the ATLAS detector"*, ATLAS VHbb Higgs Subgroup,

3 Collaboration notes with internal referee

- *"Measurement of Jet Mass in 5.02 TeV Pb+Pb and pp collisions with ATLAS"*, ATLAS Collaboration, CONF-2018-014
- *"Measurement of the azimuthal anisotropy of charged particle production in Xe+Xe collisions at sNN=5.44 TeV with the ATLAS detector"*, ATLAS Collaboration, CONF-2018-011
- *"Observation of H->bb decays and VH production with the ATLAS detector"*, ATLAS Collaboration, ATLAS-CONF-2018-036

Presentations

6 Oral presentations in international conferences

- Rute Pedro: ***"Optics robustness of the ATLAS Tile Calorimeter"***, 2018-05-21, CALOR 2018-18th Internaltional Conference on Calorimetry in Particle PhysicsUniversity of Oregon
- Filipe Veloso: ***"Searches for rare top quark couplings with the ATLAS detector"***, 2018-05-29, CIPANP 2018: Thirteenth Conference on the Intersections of Particle and Nuclear Physics, Palm Springs, USA
- Ricardo Gonçalo: ***"LHC Highlights in Top and Higgs Physics"***, 2018-06-19, BEACH 2018 – XIII International Conference on Beauty, Charm and Hyperon Hadrons, Peniche
- Helena Santos: ***"Quarkonia produced in Heavy Ions from the ATLAS Experiment"***, 2018-06-22, BEACH2018, Peniche
- Ricardo Gonçalo: ***"Latest Higgs Results from ATLAS"***, 2018-09-06, Workshop on Multi-Higgs Models 2018, Instituto Superior Tecnico
- Emanuel Gouveia: ***"Measuring the CP structure of the top Yukawa coupling in ttH events at the LHC"***, 2018-09-16, 11th International Workshop on Top Quark Physics, Bad Neuenahr, Germany

4 Poster presentations in international conferences

- Ana Peixoto: ***"Search for new interaction at the top quark section"***, 2018-05-04, 1st IGFAE/LIP Workshop, Braga (Portugal)
- Emanuel Gouveia: ***"Triggering on hadronic signatures in the ATLAS experiment - Developments for 2017 and 2018"***, 2018-07-09, 23rd International Conference on Computing in High Energy and Nuclear Physics, Sofia - Bulgaria
- Tiago Vale: ***"Search for vector-like quarks decaying to a Z boson with the ATLAS experiment"***, 2018-09-16, 11th International Workshop on Top Quark Physics, Bad Neuenahr, Germany
- Ana Peixoto: ***"Search for flavour-changing neutral currents tZ interactions in proton-proton collisions at sqrt(s) = 13 TeV collected with the ATLAS detector"***, 2018-09-16, 11th International Workshop on Top Quark Physics, Bad Neuenahr, Germany

4 Oral presentations in international meetings

- Emanuel Gouveia: ***"Search for ttH production and measurement of top-Higgs coupling properties with the ATLAS experiment"***, 2018-05-04, 1st Joint Workshop IGFAE/LIP, Braga , Portugal
- Patricia Conde: ***"ATLAS Overview"***, 2018-05-04, First joint workshop IGFAE/LIP, Braga, Portugal
- Nuno Castro: ***"Comparison of ATLAS and CMS t->Zq searches"***, 2018-05-15, LHC TOP WG meeting, CERN
- Nuno Castro: ***"Continuous integration in gitlab - implementation of a work flow for LATEX-based papers"***, 2018-08-04, BayTeX annual meeting, Nürnberg, Germany

8 Presentations in national conferences

- Susana Santos: ***"t bar tH dileptonic production at ATLAS"***, 2018-02-16, Jornadas do LIP 2018, Évora
- David Fernandes: ***"Measurement of the branching ratio of t rightarrow sW with ATLAS"***, 2018-02-16, Jornadas do LIP 2018, Évora
- Bruno Galhardo: ***"Search for FCNC t to qZ decays"***, 2018-02-16, Jornadas do LIP 2018, Évora
- Patricia Conde: ***"ATLAS Overview"***, 2018-02-16, Jornadas do LIP, Evora
- Rute Pedro: ***"Higgs Physics at ATLAS/LIP"***, 2018-02-16, Jornadas do LIP 2018, Évora
- Nuno Castro: ***"Data Science in Particle Physics"***, 2018-03-15, Data science in (astro)particle physics and the bridge to industry Symposium, Lisboa
- Emanuel Gouveia: ***"ttH production and Higgs-top coupling properties at the LHC with the ATLAS experiment"***, 2018-06-28, 4th IDPASC Students Workshop, Coimbra
- Ricardo Gonçalo: ***"Desafios e oportunidades no upgrade do HL-LHC do CERN"***, 2018-07-03, Ciência 2018, Lisboa

11 Poster presentations in national conferences

- Emanuel Gouveia: ***"Improvement of fake jet rejection at trigger level using the TileCal gap/crack scintillators"***, 2018-02-16, Jornadas LIP 2018, Évora - Portugal
- Emanuel Gouveia: ***"Probing the CP nature of the Higgs couplings in ttH events at the LHC"***, 2018-02-16, Jornadas LIP 2018, Évora - Portugal
- Ana Carvalho: ***"Higgs trilinear coupling in boosted di Higgs production"***, 2018-02-16, Jornadas do LIP, Évora, Portugal
- António Costa: ***"ttH production in ATLAS Phase-II"***, 2018-02-16, Jornadas do LIP, Évora, Portugal
- Tiago Vale: ***"Search for vector-like quarks decaying to a Z boson with the ATLAS experiment"***, 2018-02-16, Jornadas do LIP 2018, Évora, Portugal
- Ana Peixoto: ***"Search for tZ production via Flavour Changing Neutral Currents with the ATLAS Experiment at 13 TeV"***, 2018-02-16, Jornadas do LIP 2018, Évora, Portugal
- Rui Faísca Pereira: ***"ATLAS heavy-ion studies at LIP"***, 2018-02-16, Jornadas LIP 2018, Évora, Portugal
- Bruno Galhardo: ***"Top quark Physics"***, 2018-02-16, Jornadas do LIP 2018, Évora
- João Gentil: ***"LOMaC - Laboratory for Optics and Scintillating Materials"***, 2018-02-17, Jornadas LIP, Évora, Portugal
- Tiago Vale: ***"Search for heavy fermions with the ATLAS experiment"***, 2018-06-28, 4th IDPASC Workshop, Coimbra, Portugal
- Ana Peixoto: ***"Search for tZ production via Flavour Changing Neutral Currents with the ATLAS Experiment at 13 TeV"***, 2018-06-28, 4th IDPASC Workshop, Coimbra

10 Seminars

- Patricia Conde: ***"The Higgs boson adventure continues..."***, 2018-02-05, Third Lisbon mini-school on Particle and Astroparticle Physics, Oeiras
- Ricardo Gonçalo: ***"Introduction to Higgs Physics at the LHC"***, 2018-04-02, IDPASC course on Physics at the LHC, LIP-Lisboa
- Patricia Conde: ***"Results from the Higgs Searches at the LHC"***, 2018-04-04, Physics at the LHC, LIP
- Nuno Castro: ***"Probing the Standard Model and beyond with the top quark"***, 2018-04-06, IIHE Seminar, IIHE - Brussels~
- Helena Santos: ***"ATLAS-OpenData"***, 2018-07-11, LIP Summer Student Programme, LIP-Lisboa
- Ricardo Gonçalo: ***"A Nova Fisica e o Bosao de Higgs"***, 2018-07-13, LIP Summer Student Programme, LIP-Lisboa
- Patricia Conde: ***"O bosão de Higgs"***, 2018-07-13, LIP Summer Student Programme, LIP-Lisboa
- Helena Santos: ***"Heavy ions"***, 2018-07-13, LIP Summer Student Programme, LIP-Lisboa

- Ricardo Gonçalo: *"News from the Higgs Front"*, 2018-11-08, Seminários LIP, LIP-Lisboa
- Ricardo Gonçalo: *"O bosao de Higgs e eu"*, 2018-12-12, Seminários de Engenharia Física, FCTUC, Coimbra

18 Outreach seminars

- Nuno Castro: ***"A Física de Partículas, o Universo e o CERN"***, 2018-01-12, , Escola Secundária de Caldas das Taipas, Guimarães
- Ricardo Gonçalo: ***"Tornar visivel o invisivel"***, 2018-02-21, International Particle Physics Masterclass, UTAD, Bragança
- Patricia Conde: ***"A Física do CERN"***, 2018-02-24, Masterclasses of Particle Physics, IST/Lisboa
- João Gentil: ***"Palestra sobre detectores e aceleradores"***, 2018-03-10, 14a International Masterclasses in Particle Physics, Universidade de Evora
- Ricardo Gonçalo: ***"Introducao a Fisica de Particulas"***, 2018-03-14, International Particle Physics Masterclass, Universidade dos Açores
- Ricardo Gonçalo: ***"Introducao a Fisica de Particulas"***, 2018-03-17, International Particle Physics Masterclass, FCUL, Lisboa
- Bruno Galhardo: ***"accelerating science"***, 2018-03-17, Masterclasses, Coimbra
- Helena Santos: ***"Vizualisador de Eventos - HYPATIA"***, 2018-03-17, International Masterclasses in Particle Physics, FCUL, Lisboa
- Bruno Galhardo: ***"accelerating science"***, 2018-03-24, Masterclasses, Aveiro
- João Gentil: ***"Palestra sobre detectores e aceleradores"***, 2018-03-24, 14a International Masterclasses in Particle Physics 2018, Instituto Politecnico de Beja
- Patricia Conde: ***"Organization of the CERN Collaborations"***, 2018-03-26, Mestrado em Comunicação e Ciência, IST/LIP
- Nuno Castro: ***"O bosão de Higgs - o que é e como foi descoberto"***, 2018-05-02, , Escola Básica de Vale do Este, Cruz, Vila Nova de Famalicão
- Patricia Conde: ***"Para alem do bosão de Higgs?"***, 2018-06-29, Micropalestras sobre supertemas, IST, Lisboa
- Ricardo Gonçalo: ***"Introducao a Fisica de Particulas"***, 2018-07-02, Ciencia Viva - Ocupação Científica de Jovens nas Férias, LIP-Lisboa
- Rui Faísca Pereira: ***"HYPATIA Hands On"***, 2018-07-09, Estágios de Verão LIP 2018, FCUL, Lisboa, Portugal
- Nuno Castro: ***"A experiência ATLAS do CERN"***, 2018-09-06, 12ª Escola de Professores no CERN em Língua Portuguesa, CERN, Geneva
- Ricardo Gonçalo: ***"O Vazio e o Bosão de Higgs"***, 2018-10-11, ESERO 2018, Escola Secundária António Damásio, Lisboa
- Filipe Veloso: ***"Partículas elementares e forças fundamentais: o LHC"***, 2018-12-10, Escola Secundária José Falcão, Coimbra

Organized Events

1 Collaboration Meetings

- ***"7th ATLAS single top-quark workshop"***, [Coll-Mtg] 2018-12-10 / 2018-12-12, Braga

Theses

5 PhD

- André Pereira: ***"An efficient particle physics data analysis framework for homogeneous and heterogeneous platforms"***, 2013-09-01 , (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)
- 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)

10 Master

- Ana Carvalho: ***"Search for highly boosted Higgs bosons decaying to b quarks in ATLAS"***, 2017-09-26 / 2018-01-12, (finished)
- Aidan Kelly: ***"Study of the ATLAS sensibility to new physics contributions in the Hbb and Hbby vertices"***, 2017-09-01 / 2018-08-28, (finished)
- David Fernandes: ***"Pesquisa de decaimentos raros do quark top na experiência ATLAS do LHC"***, 2016-08-23 / 2018-09-10, (finished)
- António Costa: ***"Produção associada do bosão de Higgs com quarks top em ATLAS no LHC"***, 2017-09-26 / 2018-11-12, (finished)
- Ricardo Barrué: ***"Study of the ATLAS sensibility to anomalous Spin/CP components in the HWW vertex"***, 2017-01-01 / 2019-03-31, (ongoing)
- Rui Martins: ***"Background studies for the ttH searches"***, 2015-10-01 , (ongoing)
- Maura Teixeira: ***"Search for monotop events with ATLAS full run-2 data"***, 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)
- André Reigoto: ***"Probing the Higgs Top quark couplings in ttH dileptonic events with four or more b jets at the LHC"***, 2016-11-30 , (ongoing)

CMS

Collaboration in the CMS experiment at CERN

Principal Investigator:
João Varela (95)

11 *Researcher(s):*
Agostino di Francesco (33), Cristóvão Silva (100), Eliza Costa (75), Jonathan Hollar (100), João Seixas (30), Ksenia Shchelina (*), Michele Gallinaro (100), Nuno Leonardo (100), Pedrame Bargassa (100), Pietro Faccioli (20), Tahereh Niknejad (100)

2 *Technician(s):*
José Carlos Silva (60), Rui Pereira da Silva (30)

6 *PhD Student(s):*
Bruno Galinhas (20), Diogo de Bastos (100), Giles Strong (100), Mariana Araujo (92), Oleksii Toldaiev (100), Ozlem Ozludil (59)

5 *Master Student(s):*
Beatriz Ribeiro Lopes (48), Bruno Alves (80), José Neves (43), Júlia Silva (48), Viorel Dubceac (100)

14 *Trainee(s):*
Ana Rita Gaspar, Beatriz Pereira Lopes, Joana Vital, João Gonçalves, João Lourenço, José Neves, Luís Sintra, Maria Faria, Miguel Afonso, Miguel Bengala, Nelson Rebelo, Ricardo Cipriano, Rodrigo Santo, Tomás Alvim

4 *External collaborator(s):*
André David, Kai-Feng Chen, Pedro Ferreira da Silva, Stefaan Tavernier

Total FTE:
17.3

(*) starting in 2019

Article(s) in international journals:
7 Direct contribution
145 Indirect contribution
Internal note(s):
9 Collaboration note(s)
Proposal(s):
2
International conference(s):
13 Oral presentation(s)
1 Poster(s)
8 Proceeding(s)
International meeting(s):
4 Oral presentation(s)
National conference(s):
5 Oral presentation(s)
Collaboration meeting(s):
59 Oral presentation(s)
Seminar(s):
20 Seminar(s)
5 Outreach seminar(s)
Completed theses:
1 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 rare B_s meson decays; the measurement of the psi and upsilon polarizations; and the searches for a charged Higgs and a top squark. A LIP group member has served as Deputy Spokesperson of the Collaboration in 2012-13.

After a two-year shutdown the LHC resumed operation in 2015 with the energy increased to 13 TeV. In preparation for the new beam conditions, the LIP group contributed to the upgrade of the experiment by building and installing a large set of High-Speed Optical Links (oSLB-oRM) that interface the ECAL electronics to the trigger system.

The LIP group led the development of the new CTPPS forward proton spectrometer, which took physics data integrated in CMS in 2016-17-18. CTPPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at high luminosity on a regular basis. Since 2018 the project has been organized as a fully integrated subdetector of CMS, named PPS, with one LIP member serving as deputy Project Manager.

The group is actively involved and contributing to the physics analysis of the new data in the areas of top physics, Higgs physics, B physics, SUSY physics, and PPS physics. A member of the LIP group has coordinated the CMS B Physics group in 2014-2016. Two former members of the group, now with CERN, have also coordinated in 2015-16 the CMS Higgs and Top physics groups.

The group is participating in the CMS Phase 2 Upgrade in view of the High-Luminosity LHC. R&D in collaboration with Portuguese industry is being pursued in view of the development of microelectronics blocks for the frontend readout systems of the MIP Timing Detector (MTD), the Electromagnetic Calorimeter (ECAL), and the High Granularity Calorimeter (HGCAL). The LIP group is taking a leading responsibility in the development of the readout system of the MTD barrel. The development, prototyping and integration with detector modules is being performed in the TagusLIP laboratory.

Sources of funding

Code	Amount	Dates	Description
IF/01454/2013/CP1172/CT0003	50.000 €	2014-01-01 / 2018-12-31	Expl. 2014 NL - IF/01454/2013/CP1172/CT0003
IF/00772/2014/CP1248/CT0002	50.000 €	2015-01-01 / 2019-12-31	Expl. 2015 PB - IF/00772/2014/CP1248/CT0002
AMVA4NewPhysics - 675440	238.356 €	2015-09-01 / 2019-08-31	Advanced Multi-Variate Analysis for New Physics Searches at LHC
CERN/FIS-PAR/0006/2017	345.000 €	2017-08-01 / 2019-07-31	Collaboration in the CMS experiment at CERN

Total: 683.356 €

CMS

Lines of work and team organization

Lines of work

The LIP/CMS group structure follows the main lines of activity:

1) Proton-proton physics analysis:

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

2) Heavy-ion physics analysis:

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

3) New detector developments for the CMS Upgrade program:

The objective of this sub-group 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 CMS sub-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 PI of the group is Joao Varela. He has 30 years of research experience in Particle Physics collaborations at CERN. The senior researchers of the LIP-CMS group are the following: Joao Seixas, Michele Gallinaro, Nuno Leonardo, Pedrame Bargassa, Jonathan Hollar. The senior engineer for electronics developments is J.C. Silva.

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

- LIP/CMS group coordinator - J. Varela
- LIP/CMS deputy group coordinator - J. Seixas
- Physics Analysis Coordinators - M. Gallinaro, N. Leonardo, P. Bargassa, J. Hollar, J. Seixas
- Upgrade coordinator: J. Varela
- ECAL coordinator - J. C. Silva
- PPS coordinator - J. Hollar
- Computing link person - D. Bastos

The CMS Collaboration has about 3500 members from 200 institutes in 41 nations. The LIP group members have presently the following coordination positions in the CMS Collaboration structure:

- PPS Deputy Project Manager, since 2018 (J. Hollar)
- PPS Physics Interfaces co-coordinator, since 2018 (M. Gallinaro)
- PPS Protons POG co-coordinator, since 2019 (K. Shchelina)
- ECAL electronics coordinator (Level-2), since 2011 (J. C. Silva)
- MTD barrel (BTL) readout system co-coordinator, since 2018 (J. Varela)

LIP group members participate in the following CMS structures:

- CMS Collaboration Board (J. Varela and J. Seixas)
- CMS Finance Board (J. Varela)
- ECAL Institution and Finance Board (J.C. Silva)
- PPS Steering Committee (J. Hollar, M. Gallinaro, K. Shchelina)
- PPS, MTD and HGCAL Institution Boards (J. Varela)
- Publication Board, Top and B physics (N.Leonardo)

Members of the LIP group are regularly selected to participate in Analysis Review Committees (ARC).

Stated objectives for past year

The LIP group had planned to participate in the following areas of physics analysis and detectors activities in 2018:

TASK 1: PHYSICS ANALYSIS:

1) Higgs physics

1. Search for di-Higgs events in resonant or non-resonant modes in di-tau and bbar final states (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 the quartic gauge coupling ggWW using the CTPPS spectrometer.

3) B physics

1. Search for rare decays and measurement of heavy flavour production.

4) New physics in top like events

1. Search for charged Higgs and for Dark Matter associated to Higgs boson

5) SUSY physics

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

6) Heavy-ion physics and QCD

1. study of the sequential suppression of quarkonia in nucleus-nucleus collisions

TASK 2: R&D PHASE 2 UPGRADE

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

1. Development and production of the BTL ASIC TOFHiR1 in CMOS 110 nm technology.

2) R&D in the ECAL frontend readout system

1. Development of a new 160MS/s low power ADC, in collaboration with INFN Torino and Portuguese industry.

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

1. Negotiation of the supply by Portuguese industry of low voltage regulator (LVR) resistant to radiation.
2. Development of algorithms for the HGCAL L1 trigger.

TASK 3: EXPERIMENT OPERATION AND MAINTENANCE

1) ECAL

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

2) CTPPS

1. Operation and maintenance of the DAQ system of the CTPPS project.

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 CTPPS.

4) Computing:

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

Achievements and responsibilities during the past year

The LIP/CMS group made major scientific contributions in the following areas:

1) Physics

a) Top physics

The analysis of top events with taus in the final state at 13 TeV (Run 2 data) is progressing (PhD student A. Toldayev, M. Gallinaro). The LIP/CMS group is pursuing the measurement of the cross section in the dilepton final state including a tau lepton by using a profile likelihood fit to better constrain the background composition. Preliminary results indicate an improved precision with respect to the Run1 measurements. Work is in progress to finalize the measurement and proceed to approval.

b) Search for SUSY

The analysis of the data of 2016 was finished by LIP/CMS, in collaboration with the HEPHY (Vienna). The results of the search for the lightest scalar top (stop) decaying in 4 bodies were published (JHEP 09 (2018) 065), and were recently presented at the SUSY2018 conference by a member of the group, who is also the editor of the publication (P. Bargassa). The LIP/CMS group developed a unique search of the stop based on multivariate (MVA) approach which adapts the MVA to the evolving kinematics of signal across phase-space, and which bases the prediction of the background on the output of the MVA (Post-doctoral fellow C. da Silva e Cruz, P. Bargassa). The analysis of the data of 2017 for the same search has started (PhD student D. de Bastos, P. Bargassa).

c) Search for di-Higgs events in di-tau and bbar final states

Regression and classification studies in di-Higgs production were pursued in 2018 with simulated CMS samples to validate the algorithms previously developed with DELPHES data. Di-Higgs production in the “tautaubb” final state, with subsequent leptonic and hadronic decays of the tau leptons, is scrutinized. The studies are performed on CMS data using advanced "machine learning" analysis techniques with the goal of improving the separation of signal and background. Work is developed in the context of the Tau Id POG, and Higgs HH working group. Projections for the expected sensitivity of this search were also estimated for the HL-LHC conditions and the results summarized in the Yellow-Report (CMS-FTR-18-019 and arXiv:1902.00134). This activity is carried out in the frame 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 Yellow Report.

d) Study of SM Higgs in the di-tau decay mode

The analysis of the data of 2016 has started by LIP/CMS, in collaboration with the KIT (Karlsruhe) group. Multi-class Neural Networks (NN) are used to disentangle signal from different background processes, and their output distribution are fitted to data to extract the strength of signal. A member of the group (P. Bargassa) synchronized his software with KIT, and performed studies on the optimization of the internal parameters of the NN. With the help of an undergraduate student (L. Sintra, IST), he has started studies to improve the performance of the multi-class NN by better controlling the $Z \rightarrow 2tau$ background which is dominating the signal in this final state.

e) Search for Dark Matter associated to a Higgs boson

Members of the group (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 Politecnico of Bari and was approved in 2018 (CMS-EXO-18-009). The final results are being summarized in a paper that includes other Higgs boson decay channels (CMS-EXO-18-011).

f) Search for rare decays of the Higgs boson into quarkonium

The search for the rare decays of the Higgs and Z bosons into quarkonia plus photon was implemented (E.Melo, N.Leonardo, with collaborators at UERJ and Taiwan). The jpsi channel has been published, while the upsilon channel is finalized and under internal review. These exclusive decay channels provide complementary paths to access the quark Yukawa couplings, a challenging task at the (HL-)LHC, and potential new physics. One undergraduate student (M. Afonso) developed a summer internship in the project.

g) Search for rare decays and measurement of heavy flavour

The B→μμ analysis with Run2 data has remained a priority. Associated b-production studies were pursued. The study of b-quark fragmentation-fraction ratio, input to the measurement of the Bs→μμ branching fraction, has been performed. The absence of kinematic dependence of fs/fd was established, reflecting as a considerable improvement in the measurement's dominant systematics. The student B. Alves defended (with grade 19/20) at IST in May 2018 his MSc thesis entitled "Measurement of b-quark fragmentation fraction ratios at the CMS experiment: a key ingredient for the Bs→μμ rare decay analysis" [https://cds.cern.ch/record/2649927]. While the 2016 analysis is under internal review by the collaboration, the group initiated the study of the 2017 data set. The group (O. Ozcelik, N. Leonardo, with collaborator in Taiwan) delivered the CMS HL-LHC projections of the B→μμ analysis, and reported them as part of the HL/HE-LHC yellow report submitted as input for ESPP update process. One undergraduate student (M. Faria) developed a summer internship in the project.

h) Search for exclusive two-photon production using the CTPPS spectrometer

Members of the LIP group (L. Llorett, J. Hollar, K. Shchelina) led the first analysis of dilepton production via two-photon interactions with tagged forward protons using the CTPPS spectrometer, which was published in 2018 [JHEP 1807 (2018) 153]. 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 (M. Gallinaro, B. Ribeiro Lopes, J. Hollar) using the CTPPS data.

i) Quarkonia polarization

The activity of the group (P. Faccioli, J. Seixas, M. Araujo) is centered in two connected lines of research. On the one hand the group is involved in phenomenological studies aimed at interpreting quarkonium measurements towards an understanding of the mechanisms of hadron formation in QCD. From such studies stemmed important results that provide guidelines for experimental studies. More recently [Phys. Lett. B 773, 476 (2017)], we have brought to light a previously unnoticed observation: the existing LHC quarkonium production measurements reveal that all quarkonium states tend to follow one universal momentum scaling pattern. This lead to a complete program of measurements. On the other hand, the group is experimentally pursuing the measurement of the polarization of the χc1 and χc2 states with CMS data, in collaboration with the Austrian HEPHY group and the Mexican group of CIEA/IPN. The χc1 and χc2 analysis is already quite advanced and is expected to be completed during the following months.

j) B mesons as novel probes of the QGP

The CMS detector offers unmatched capability for exploring exclusive heavy flavor decays in the heavy ion environment. The group (J. Silva, N. Leonardo, with collaborators at MIT and Purdue) is taking part in the investigation of the first B meson signals in PbPb data. The analysis of the PbPb 2015 data was published providing evidence for the Bs signal. The exploration of the full Run2 PbPb dataset that has now been collected is being pursued as an MSc thesis which should allow for the observation of Bs and other HF states in ion data. One undergraduate student (J. Lourenço) developed a summer internship where the phenomenon of sequential quarkonium (Υ) suppression was studied with 2015 5TeV PbPb data.

2) 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 (A. Toldaiev, G. Strong) and forward proton alignment (G. Strong) and CTPPS high-level trigger (C. Cruz e Silva)

3) CTPPS installation, operation and physics

Under the leadership of a LIP member serving as overall CTPPS Project Manager (J. Varela), CTPPS collected over 100 fb^{-1} of data from 2016-2018 in Run 2 of the LHC. The LIP group had leading roles in the CTPPS DAQ system (J. Hollar) and the Timing detectors (M. Gallinaro). LIP also made major contributions to the timing detector electronics, online software, and detector operations. Since 2018 the project has been organized as a fully integrated subdetector of CMS, named PPS, with one LIP member serving as deputy Project Manager (J. Hollar). Several members of the LIP group are actively involved in physics analyses using the PPS data (K. Shchelina, M. Gallinaro, B. Ribeiro Lopes, J. Hollar), and had leading roles in the first PPS physics paper, published in 2018.

4) CMS Phase 2

Upgrade (HL-LHC)
In 2018 the activities of the LIP-CMS group towards the CMS Phase 2 Upgrade for operation at HL-LHC entered in full swing following the approval by FCT and the Minister of Science and Technology of the participation of LIP in the CMS Phase 2 Upgrade. The LIP group increased the involvement in the MIP Timing Detector (MTD) assuming the main responsibility in the development and production of the front-end readout system of the barrel detector (BTL). The development of the front-end ASIC (TOFHIR) was pursued in collaboration with the PETsys start-up. PETsys is responsible for the microelectronics ASIC design and the LIP-CMS group develops the integration of the chip in front-end boards and detector modules. These activities make use of the TagusLIP laboratory infrastructure.

The TOFHIR ASIC is derived from the TOFPET2 chip developed for TOF-PET applications using LYSO crystals coupled to SiPMs. The TOFPET2 design is being adapted to match the requirements of the barrel timing layer, in particular the high signal rate and the tolerance to radiation. The strategy being pursued in direction of the new TOFHIR ASIC has two steps: (1) the development of the TOFHIR1 chip in the same CMOS technology of TOFPET2 (UMC 110 nm) implementing the main features required by BTL and allowing the development of final detector modules and the validation of system integration within a short schedule; (2) the development of the TOFHIR2 chip achieved by translating TOFHIR1 to the CMOS 130 nm technology provided by TSMC foundry, that is less sensitive to radiation, and revising the TOFHIR1 blocks for radiation tolerance. Important functionality related to SiPM dark noise cancellation is only implemented in TOFHIR2. The TOFHIR1 chips were received from the foundry in December 2018 and are being tested. The first prototype of the TOFHIR2 ASIC is expected to be available in the end 2019.

In collaboration of INFN/Torino, LIP is contributing to the new frontend digitizer and data transmission chip for the upgrade of the ECAL detector (LiTE-DTU: Lisbon-Torino ECAL Data Transmission Unit). LIP led the technical specification of the new high-end, low-noise and low-power ADC (12-bit 160 Ms/s) for integration in the LiTE-DTU chip. After a market survey performed by LIP, the Portuguese branch of the company S3-Group specialized in analog to digital converters was selected. The contract for an IP Block with the required ADC functionality was placed through CERN profiting from the help of CERN's purchasing department to define the terms of the contract. The order was placed in the end March 2018 and the delivery of the final IP block (GDS2 file) was done in the end October 2018. The development process was followed closely through meetings every two weeks attended by the S3 project coordinator and engineers, and by weekly written reports provided by the company. The IP block has been integrated in the LiTE-DTU chip (CMOS 65 nm) at INFN/Torino and was submitted to a MPW run of the TSMC foundry.

The specification for a Low-Voltage Regulator for the HGCAL front-end was prepared in collaboration with CERN Microelectronics. A Price Inquiry was organized by CERN's purchase department. Presently the negotiations for the supply of the LVR are being pursued.

5) Outreach & advanced training

Group members take part in outreach activities for high school and university students (MasterClasses, CERN visits, InsideViews, student sessions at LIP room at IST). One group member coordinated the LIP summer internship program (that has attracted 60+ students to LIP, 14 of which were integrated in the CMS group), and served as co-coordinator of advanced training at LIP.

Group members organized an outreach event on Artificial Intelligence and Particle Physics at the National Library that attracted more than 300 people.

Lines of work and objectives for next year

The LIP/CMS group activities in 2019 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 di-tau and bbar final states (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) New physics in top like events

1. Search for Dark Matter associated to Higgs boson.

5) SUSY physics

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

6) Heavy-ion physics and QCD:

1. When more statistics is available in the CMS Heavy Ion program, there are interesting applications of the measurement of the polarization of the χc1 and χc2 states to the study of the sequential suppression of quarkonia in nucleus-nucleus collisions which we aim to pursue.
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 TOFHiR 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.

Medium-term (3-5 years) prospects

In the period 2019-23 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 Analysis of different topics profiting from the large amount of data expected until the end of Run 3 (2023). The objective is to fully exploit the discovery opportunities offered by the LHC. The activity is organized in main physics domains, namely Higgs Physics, Top Quark Physics, B Physics, Quarkonia and Heavy Ions, SUSY Physics and Photon-Photon Physics, spanning from the search for new particles and phenomena beyond the standard Model (SM) to the precise measurements of the SM properties.

The group will be responsible for the upgrade of the data acquisition system of the Precision Proton Spectrometer (PPS) in view of the Run 3 data taking, and will contribute to the maintenance and operation of the sub-detectors Precision Proton Spectrometer (PPS) and Electromagnetic Calorimeter (ECAL).

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. The detailed study of the 125 GeV Higgs is a scientific imperative that must be pursued to a much higher level of statistical precision than it is available today. Until the end of Run 3 in 2023, 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 and Upgrades

Precision Proton Spectrometer (PPS)

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

During Long Shutdown 2, all detector packages will be 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 2019-2023, LIP continues 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 2026. In order to meet the experimental challenges of this unprecedented proton-proton luminosity, the CMS collaboration will undertake the Phase 2 upgrade program to maintain the excellent performance of the detector.

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

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

The LIP/CMS 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 analysis. Leadership in different areas of the front readout systems of the Phase II Upgrade.

Weaknesses

Difficulty in attracting foreign postdocs 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 a large fraction of the senior physicists of the group.

Publications

7 Articles in international journals

(with direct contribution from the team)

- ***"Universal kinematic scaling as a probe of factorized long-distance effects in high-energy quarkonium production"***, Pietro Faccioli, Carlos Lourenco, Mariana Araujo, Joao Seixas, Eur. Phys. J. C 78 (2018) 118
- ***"From identical S- and P-wave p(T) spectra to maximally distinct polarizations: probing NRQCD with chi states"***, Pietro Faccioli, Carlos Lourenco, Mariana Araujo, Joao Seixas, Ilse Kraetschmer, Valentin Knunz, Eur. Phys. J. C 78 (2018) 268
- ***"Observation of proton-tagged, central (semi)exclusive production of high-mass lepton pairs in pp collisions at 13 TeV with the CMS-TOTEM precision proton spectrometer"***, CMS and TOTEM Collaborations, J. High Energy Phys. 7 (2018) 153
- ***"Charged particle timing at sub-25 picosecond precision: the PICOSEC detection concept"***, M. Gallinaro et al., arXiv:1806.04395
- ***"Search for top squarks decaying via four-body or chargino-mediated modes in single-lepton final states in proton-proton collisions at $sqrt{s}$=13~TeV"***, P. Bargassa, C. Beirao et al, J. High Energy Phys. 9 (2018) 065
- ***"PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector"***, M. Gallinaro et al., Nucl. Instrum. Meth. A 903, 317 (2018)
- ***"Deep Diffused APDs for Charged Particle Timing Applications: Performance after Neutron Irradiation"***, M. Gallinaro et al., arXiv:1812.08433

8 International Conference Proceedings

- *"The CMS-TOTEM Precision Proton Spectrometer and first physics results, to appear in Proceedings of ICHEP 2018"*, J. Hollar for the CMS and TOTEM collaborations, CMS CR-2018/248
- *"Characterization of irradiated APDs for picosecond time measurements"*, M. Gallinaro et al., J. Instrum. 13 (2018) C01041
- *"Looking forward: exclusive dilepton production with a leading proton"*, M. Gallinaro (for the CMS and TOTEM collaborations), CMS CR-2018/186
- *"Rare H and Z decays to quarkonia with CMS"*, E.Melo, CMS CR-2018/222
- *"Heavy quark probes of QCD"*, N. Leonardo, PoS(ICHEP2018)216
- *"Searches for Higgs bosons with dark matter at the Large Hadron Collider"*, M. Gallinaro (for the ATLAS and CMS collaborations), CMS CR-2018/380
- *"Flavor physics & beyond, a concluding review"*, N.Leonardo, JPCS 1137 (BEACH)
- *"Photon-photon and photon-proton measurements with forward proton taggers in CMS+TOTEM"*, J. Hollar, on behalf of the CMS and TOTEM Collaborations, CERN Proceedings, [S.l.], v. 1, p. 1, dec. 2018

2 Proposals

- *"Opportunities in Flavour Physics at the HL-LHC and HE-LHC"*, N.Leonardo, O.Ozcelik, et al, CERN-LPCC-2018-05
- *"Higgs Physics at the HL-LHC and HE-LHC"*, M. Bengala, A.J. Costa, M. Gallinaro, R. Gonçalo, E. Gouveia, P.C. Muiño, R Santo, and G. Strong, et al., CERN-LPCC-2018-04

6 Internal notes

- *"Searches for Z and Higgs boson decaying into Upsilon plus gamma in pp collision at 13 TeV with 2016 data"*, E.Melo, N.Leonardo, et al, CMS AN-2018/032
- *"Measurement of b-quark fragmentation fractions"*, N.Leonardo, B.Galinhas, B.Alves, CMS AN-2017/168
- *"Rare B decays studies at HL-LHC"*, O.Ozcelik, N.Leonardo,J.Chen, CMS AN-2018/167
- *"Search for Dark Matter produced in association with a Higgs boson in the four-lepton final state at 13 TeV"*, M. Gallinaro , J. Goncalves et al., CMS AN-2016/328
- *"Searching for exclusively produced top quark pairs"*, B. Ribeiro Lopes, P. Ferreira da Silva, J. Hollar, M. Gallinaro, CMS AN-2018/239
- *"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

3 Collaboration notes with internal referee

- *"Search for Dark Matter produced in association with a Higgs boson in the four-lepton final state at 13 TeV"*, M. Gallinaro , J. Goncalves et al., CMS PAS EXO-18-009
- *"Measurement of rare B→μ+μ− decays with the Phase-2 upgraded CMS detector at the HL-LHC"*, CMS Collaboration, CMS-PAS-FTR-18-013
- *"Prospects for HH measurements at the HL-LHC"*, M. Bengala, M. Gallinaro, R Santo, and G. Strong, et al., CMS-PAS-FTR-18-019

Presentations

13 Oral presentations in international conferences

- Michele Gallinaro: *"Timing layer at CMS: Precision timing at the LHC"*, 2018-03-08, 4th FAST Annual meeting, Bucharest, Romania
- Jonathan Hollar: *"Physics results with CT-PPS and perspectives"*, 2018-05-25, 4th Elba Workshop on Forward Physics @ LHC Energy, La Biodola, Elba, Italy
- Michele Gallinaro: *"The Precision Proton Spectrometer at the LHC"*, 2018-05-26, 4th workshop on Detectors for Forward Physics at the LHC, La Biodola, Elba, Italy
- Michele Gallinaro: *"Exclusive dilepton production with a leading proton"*, 2018-06-18, 13th International Workshop on Beauty, Charm, and Hyperon Hadrons (BEACH2018), Peniche, Portugal
- Eliza Costa: *"Rare H,Z decays to quarkonia"*, 2018-06-19, BEACH 2018 - XIII INTERNATIONAL CONFERENCE ON BEAUTY, CHARM AND HYPERON HADRONS, Peniche
- Nuno Leonardo: *"Conference Summary Talk"*, 2018-06-23, BEACH 2018 - XIII INTERNATIONAL CONFERENCE ON BEAUTY, CHARM AND HYPERON HADRONS, Peniche
- Jonathan Hollar: *"The CMS-TOTEM Precision Proton Spectrometer and first physics results"*, 2018-07-05, ICHEP2018: 39th International Conference on High Energy Physics, Seoul, South Korea
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- Nuno Leonardo: *"Heavy flavor production at CMS"*, 2018-07-05, ICHEP2018: 39th International Conference on High Energy Physics, Seoul, South Korea
- Pedrame Bargassa: *"3 rd generation squark searches @ CMS"*, 2018-07-23, SUS 2018, Barcelona, Spain
- Giles Strong: *"Recent developments in deep-learning applied to open HEP data"*, 2018-08-02, QCHS, Dublin, Ireland
- Nuno Leonardo: *"Rare Decays: b to sll at CMS"*, 2018-09-11, LISHEP 2018, Session C, Salvador, Brazil
- Michele Gallinaro: *"Searches for Higgs bosons with Dark Matter at the LHC"*, 2018-09-26, cHarged 2018: Prospects for Charged Higgs Discovery at Colliders, Uppsala, Sweden
- Michele Gallinaro: *"Small-x and Diffraction: Status and prospects"*, 2018-12-14, 10th International workshop on Multiple Partonic Interactions at the LHC, Perugia, Italy

1 Poster presentations in international conferences

- Giles Strong: *"Recent developments in deep-learning applied to open HEP data"*, 2018-09-25, Advanced Statistics for Physics Discovery, Padova University, italy

4 Oral presentations in international meetings

- Giles Strong: *"DNNs in regression and classification"*, 2018-01-16, hh-?bbtautau mini-workshop, INFN-Pisa, Italy
- João Varela: *"General overview of CT-PPS status and prospects"*, 2018-02-27, LHCC referees meeting, CERN
- Giles Strong: *"DNN classifiers in CMS di-Higgs search"*, 2018-06-21, 6th AMVA4NewPhysics Workshop, National and Kapodistrian University of Athens
- Giles Strong: *"Recent developments in deep-learning applied to open HEP data"*, 2018-10-17, 3rd ATLAS ML Workshop, Online

5 Presentations in national conferences

- Nuno Leonardo: *"Rare Decays & Heavy Flavor"*, 2018-02-16, Jornadas LIP, Évora
- Nuno Leonardo: *"LIP ECO3: Advanced Training Report"*, 2018-02-16, Jornadas LIP, Évora

- Oleksii Toldaiev: ***"Measurement of tt-bbltau cross-section in 13TeV CMS data and lepton universality test"***, 2018-02-16, Jornadas LIP, Évora
- Nuno Leonardo: ***"LIP Advanced Training"***, 2018-04-28, LIP Advisory meeting, LIP, Lisbon
- Oleksii Toldaiev: ***"Measurement of tt quark pair cross-section with tau lepton in final state and lepton universality test"***, 2018-06-29, IDPASC Workshop, Coimbra

20 Seminars

- Giles Strong: ***"Applications of Machine Learning to Particle Physics"***, 2018-02-07, 3rd LIP Mini-school of particle physics, Oeiras, Portugal
- Michele Gallinaro: ***"Experimental program at the LHC"***, 2018-03-06, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"Standard Model at the LHC"***, 2018-03-07, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"The Standard Model and the LHC Experimental Program"***, 2018-03-12, Doctorate Course at "Bari Politecnico" (XXXIII ciclo), Bari, Italy
- Michele Gallinaro: ***"Top quark and beyond"***, 2018-03-13, Doctorate Course at "Bari Politecnico" (XXXIII ciclo), Bari, Italy
- Michele Gallinaro: ***"SM Higgs and Beyond"***, 2018-03-14, Doctorate Course at "Bari Politecnico" (XXXIII ciclo), Bari, Italy
- Michele Gallinaro: ***"Latest Results on BSM Physics in the Higgs sector at the LHC"***, 2018-03-15, Doctorate Course at "Bari Politecnico" (XXXIII ciclo), Bari, Italy
- Michele Gallinaro: ***"Top quark: Introduction"***, 2018-03-22, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"Top quark: Properties and beyond"***, 2018-03-23, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"Higgs boson: Beyond the SM searches"***, 2018-04-11, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"Exotic processes and Dark Matter"***, 2018-05-02, Course on Physics at the LHC, LIP, Lisbon
- Nuno Leonardo: ***"Heavy flavor physics and rare decays searches"***, 2018-05-07, Course on Physics at the LHC, LIP, Lisbon
- Michele Gallinaro: ***"Highlights from the LHC: Looking forward and beyond"***, 2018-07-04, Seminar at "University of Lecce, Lecce, Italy
- Michele Gallinaro: ***"The case for precise timing at the LHC"***, 2018-07-05, Seminar at "Bari Politecnico, Bari, Italy
- Giles Strong: ***"Hyper-Parameter Optimisation Part I"***, 2018-07-06, LIP Big-Data Competency Centre Meeting, Online
- Michele Gallinaro: ***"Probing the SM at the LHC"***, 2018-07-10, Summer student program, LIP, Lisbon
- Giles Strong: ***"Understanding Neural Networks"***, 2018-07-11, LIP Summer-Student Tutorials, Universidade de Lisboa
- Giles Strong: ***"Status Report of Research and PhD Progress"***, 2018-10-08, CAT, LIP, Lisboa
- Giles Strong: ***"Hyper-Parameter Optimisation Part I"***, 2018-10-31, 7th AMVA4NewPhysics Workshop, Lisboa
- Pedrame Bargassa: ***"Search for stop 4-body decays Application of MVA tools & statistical methods to Susy search"***, 2018-10-31, 7th AMVA4NewPhysics Workshop, Lisboa

5 Outreach seminars

- Nuno Leonardo: ***"Detectando o invisivel no LHC"***, 2018-02-22, International MasterClasses, Instituto Politécnico de Bragança
- Nuno Leonardo: ***"Introduction to LIP-CMS"***, 2018-02-27, LIP-CMS Inside Views, LIP, Lisboa
- Nuno Leonardo: ***"Medidas de precisão, processos raros, e QGP"***, 2018-02-27, LIP-CMS Inside Views, LIP, Lisboa
- Nuno Leonardo: ***"Are we seeing first signs of new physics at the LHC?"***, 2018-10-22, IST-LIP room, IST, Lisboa
- Nuno Leonardo: ***"A última tomada de dados do LHC Run2"***, 2018-11-20, IST-LIP room, IST, Lisboa

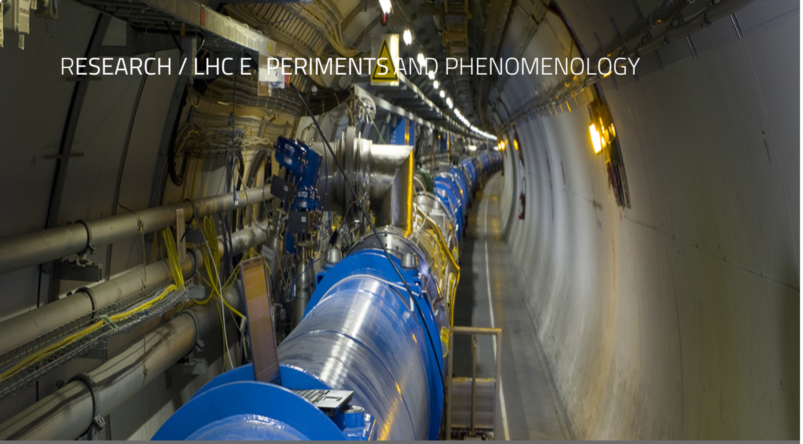
Theses

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 Araujo: ***"Study of the polarization of quarkonia states in proton collisions in the CMS experiment"***, 2018-02-12 , (ongoing)

3 Master

- Bruno Alves: ***"Search for the B0_s->mumu rare decay at the LHC"***, 2017-03-01 / 2018-06-30, (finished)
- Beatriz Ribeiro Lopes: ***"Study of the exclusive production of the top quark in the CMS experiment"***, 2018-10-07 , (ongoing)
- Júlia Silva: ***"B meson production measurement in pp and PbPb collisions at the LHC"*** (ongoing)



PHENO

Phenomenology

Principal Investigator:
Guilherme Milhano (100)

9 *Researcher(s):*
António Onofre (30), Juan P. Araque (20), Korinna Zapp (100), Liliana Apolinário (70), Miguel Fiolhais (20), Nuno Castro (30), Pietro Faccioli (50), Ricardo Gonçalo (20), Ruben Conceição (10)

3 *PhD Student(s):*
Duarte Azevedo (20), Guilherme Guedes (14), Maria Ramos (90)

7 *Master Student(s):*
André Reigoto (50), Bruno Silva (20), Filipa Peres (14), João Lourenço Barata (100), João Pedro Gonçalves (45), Pedro Lagarelhos (50), Rui Martins (50)

1 *Undergraduate Student(s):*
João Moreira

4 *External collaborator(s):*
Artur Amorim de Sousa, Juan Antonio Aguilar Saavedra, Pedro Martins Ferreira, Rui Santos

Total FTE:
9.0

Article(s) in international journals:
10 Direct contribution
Proposal(s):
3
International conference(s):
8 Oral presentation(s)
1 Poster(s)
International meeting(s):
5 Oral presentation(s)
National conference(s):
1 Oral presentation(s)
Collaboration meeting(s):
1 Oral presentation(s)
Seminar(s):
4 Seminar(s)
Completed theses:
1 Master

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. The members of the group have an excellent publication record and high international visibility. During this first year, the group focused on consolidating its research lines and identity. 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

Code	Amount	Dates	Description
CERN/FIS-PAR/0015/2017	10.000 €	2017-11-01 / 2019-10-31	Heavy Quarkonium production in hadronic interactions at LHC and AFTER@LHC
CERN/FIS-PAR/0034/2017	10.000 €	2018-01-01 / 2019-12-31	Phenomenological Studies at the LHC
CERN/FIS-PAR/0022/2017	30.000 €	2018-03-01 / 2020-02-29	Jets as quark gluon plasma probes

Total: 50.000 €

Pheno

Lines of work and team organization

At present the group has internationally recognized consolidated research activities in top-quark, Higgs, quarkonia, and heavy-ion phenomenology with a strong expertise in the development of event-generators. In addition, the group encompasses phenomenological research previously undertaken within, but independently of, the various LIP experimental groups. First steps were taken to consolidate these existing research activities (simulation of cosmic ray air showers, and Dark Matter searches). It is expected that these lines of work will be augmented in the coming year.

The activities of the group are distributed over all the three (Lisboa, Coimbra, Braga) poles of LIP. Efforts are being made to meet remotely as well as in person to increase crosstalk within the group and provide a community for the many students being trained in the group.

Stated objectives for past year

The main objective of the group for 2018 was to effectively bring the various activities carried out within the group into a coherent, yet diverse, phenomenologial research programme.

The detailed objectives were centred around heavy-ion Phenomenology, heavy quarkonium, and top-quark and Higgs physics.

Achievements and responsibilities during the past year

The previous year's stated objectives were largely met, allowing for some first decisive steps towards building a cohesive group (Braga-Lisbon co-supervision of a student) and aggregating disperse phenomenological activities (much increased cross talk with the Auger and LATTES groups).

The group's developing identity has proved attractive for both students and researchers at various career stages. The supervision of three MSc and two PhD by group members was started in 2018, and the group was approached by large number of high quality researchers wishing to apply to the highly competitive FCT Individual Call to Scientific Employment Stimulus 2017 (which took place in 2018); of the five who were supported, one was successful and will join the group in early 2019.

The group was strongly involved in the development of the scientific cases for both HL/HE-LHC and FCC. In the context of the HL/HE-LHC group members were involved in three (Standard Model, Higgs and High-density QCD with heavy-ion and proton beams) of the five working groups. Regarding the FCC, our commitment to the formulation of the physics case for heavy ion runs culminated with work by the group, in particular related to the possibility of directly accessing QGP time evolution, featuring prominently in the FCC CDR and related summary documents prepared for the upcoming discussion of the European Particle Physics Strategy Update 2018-2020.

Lines of work and objectives for next year

In 2019 the group expects to continue to deliver high impact research within its consolidated lines of work (heavy-ion phenomenology, heavy quarkonia, higgs and top Physics) and, given the substantial expected boost from the arrival of a new full-time member, extend these lines to include higher order computations in QCD and forward physics. This enlargement of scope is expected to build increased synergy both within the group - effectively linking activities in heavy ions and in SM phenomenology - and with the Cosmic Rays and LHC experimental groups.

In addition, the group will explore further synergy 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.

Finally, the group intends to continue to grow the consolidated lines of research. This will involve, in particular, continuing to attract further students and researchers to join the group, building on current expertise. It will also involve taking advantage of the first funding round that has opened since the group's formation, to seek essential funding for structural support.

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 is likely to include precision Physics at the LHC 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; 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

Opportunities

High level of interest from researchers at various levels of experience to join the group; ability to increase coherence of Phenomenology work at LIP; 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; Upcoming funding cycle may result in structural funding for the group.

Threats

Continued funding uncertainty for hiring new researchers, retaining current precariously employed researchers, and for research activities; no core group funding obtained.

Publications

10 Articles in international journals

(with direct contribution from the team)

- *"Global constraints on top quark anomalous couplings"*, Frederic Deliot, Ricardo Faria, Miguel C. N. Fiolhais, Pedro Lagarelhos, Antonio Onofre, Christopher M. Pease, Ana Vasconcelos, Phys. Rev. D 97 (2018) 013007
- *"Universal kinematic scaling as a probe of factorized long-distance effects in high-energy quarkonium production"*, Pietro Faccioli, Carlos Lourenco, Mariana Araujo, Joao Seixas, Eur. Phys. J. C 78 (2018) 118
- *"Probing the energy spectrum of hadrons in proton air interactions at ultrahigh energies through the fluctuations of the muon content of extensive air showers."*, Lorenzo Cazon, Ruben Conceição, Felix Riehn, Phys.Lett. B784 (2018) 68-76
- *"From identical S- and P-wave p(T) spectra to maximally distinct polarizations: probing NRQCD with chi states"*, Pietro Faccioli, Carlos Lourenco, Mariana Araujo, Joao Seixas, Ilse Kraetschmer, Valentin Knunz, Eur. Phys. J. C 78 (2018) 268
- *"Sensitivity of jet substructure to jet-induced medium response"*, José Guilherme Milhano, Urs Achim Wiedemann, Korinna Christine Zapp, Phys.Lett. B779 (2018) 409-413
- *"Probing the time structure of the quark-gluon plasma with top quarks"*, Liliana Apolinário, José Guilherme Milhano, Gavin P. Salam, Carlos A. Salgado, Phys.Rev.Lett. 120 (2018) no.23, 232301
- *"Novel subjet observables for jet quenching in heavy-ion collisions"*, Liliana Apolinário, José Guilherme Milhano, Mateusz Ploskon, Xiaoming Zhang, Eur.Phys.J. C78 (2018) no.6, 529
- *"CP tests of Higgs couplings in tth semileptonic events at the LHC"*, D. Azevedo, A. Onofre, F. Filthaut, and R. Gonçalo, Phys.Rev. D98 (2018) 033004
- *"The fate of quarkonia in heavy-ion collisions at LHC energies: a unified description of the sequential suppression patterns"*, Pietro Faccioli, Carlos Lourenço, Eur.Phys.J. C78 (2018) 731
- *"CP in the dark"*, Duarte Azevedo, Pedro M. Ferreira, M. Margarete Muhlleitner, Shruti Patel, Rui Santos, Jonas Wittbrodt, J. High Energy Phys. 11 (2018) 091

3 Proposals

- *"Novel tools and observables for jet physics in heavy-ion collisions"*, H. Andrews et al. , e-Print: arXiv:1808.03689 [hep-ph]
- *"Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams"*, Z. Citron et al., CERN-LPCC-2018-07
- *"FCC Conceptual Design Report Volume 1: Physics Opportunities"*, A. Abada, L. Apolinário, G. Milhano, R. Gonçalo, J.G. Mendes Saraiva, A. Carvalho, et al, CERN-ACC-2018-0056, FCC Conceptual Design Report (Submitted to Eur. Phys. J.)

Pheno

Presentations

8 Oral presentations in international conferences

- Korinna Zapp: *"Modeling of Jet Quenching in Heavy Ion Collisions (student day lecture)"*, 2018-05-13, Quark Matter 2018, Venice, Italy
- Liliana Apolinário: *"Unveiling the yoctosecond structure of the QGP with top quarks"*, 2018-05-15, Quark Matter 2018, Venice, Italy
- : *"Jet quenching in nuclear collisions: theory overview (plenary)"*, 2018-05-18, Quark Matter 2018, Venice, Italy
- Liliana Apolinário: *"Probing the time structure of the QGP (invited)"*, 2018-05-21, Probing QCD at the high energy frontier, Trento, Italy
- Liliana Apolinário: *"Overview of jet quenching and energy loss in heavy-ion collisions (invited)"*, 2018-06-05, LHCP 2018, Bologna, Italy
- Liliana Apolinário: *"Jet quenching and background effects on jet substructure"*, 2018-06-12, The Definition of Jets in a Large Background, Brookhaven National Lab, USA
- Liliana Apolinário: *"Jets in QCD matter: Monte Carlo approaches (Plenary)"*, 2018-10-01, Hard Probes 2018, Aix-le-Bains, France
- Korinna Zapp: *"Jets in QCD matter: Theory summary (plenary)"*, 2018-10-05, Hard Probes 2018, Aix-les-Bains, France

1 Poster presentations in international conferences

- Maura Barros Teixeira: *"Study of interference effects in processes with top quark flavour changing neutral currents"*, 2018-09-17, Top 2018 Workshop, Bad Neuenahr, Germany

5 Oral presentations in international meetings

- Guilherme Milhano: *"LISBON ACCORD [AND RIVET]"*, 2018-01-06, JETSCAPE workshop 2018, LBNL Berkeley, USA
- Korinna Zapp: *"Heavy ion physics (invited talk)"*, 2018-09-26, 1st Workshop on High Energy Theory and Gender, CERN
- Korinna Zapp: *"Phenomenological computing"*, 2018-10-24, Town meeting: Relativistic Heavy ion physics, CERN
- Korinna Zapp: *"SHERPA (lecture)"*, 2018-11-01, ISAPP School 2018 -- LHC meets Cosmic Rays, CERN
- Guilherme Milhano: *"Probing the time structure of the QGP with top quarks"*, 2018-12-05, Heavy Ions and Hidden Sectors , Louvain la Neuve, Belgium

1 Presentations in national conferences

- Liliana Apolinário: *"Heavy-Ions Phenomenology"*, 2018-08-30, Física 2018, Covilhã, Portugal

4 Seminars

- Liliana Apolinário: *"Dynamics of quarks and gluons in a hot and dense medium"*, 2018-02-05, 3rd Lisbon mini-school on Particle and Astroparticle Physics, Oeiras, Portugal
- Korinna Zapp: *"Deciphering jet quenching with JEWEL"*, 2018-04-11, CERN Theory Colloquium, CERN
- Pietro Faccioli: *"Quarkonium polarization from high to low pT"*, 2018-05-18, COMPASS Seminar, CERN
- Pietro Faccioli: *"Experimental patterns in LHC quarkonium production from pp to AA"*, 2018-06-05, HEPHY Seminar, Vienna, Austria

Theses

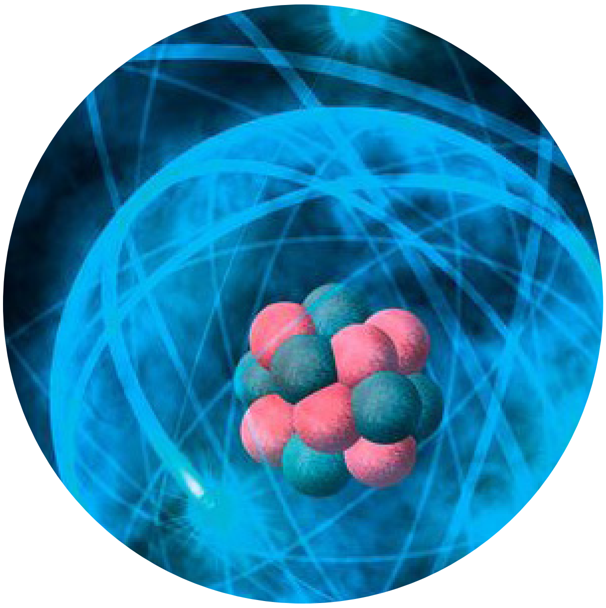
2 PhD

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)

6 Master

- João Lourenço Barata: *"Study of a New Resolution Method in the Hybrid Strong/Weak Coupling model"*, 2017-09-30 / 2018-09-30, (finished)
- Rui Martins: *"Background studies for the ttH searches"*, 2015-10-01 , (ongoing)
- Filipa Peres: *"New observables and techniques for the study of jets in hadron collisions"*, 2018-09-15 , (ongoing)
- Bruno Silva: *"Searching for jet quenching in small systems"*, 2018-11-01 , (ongoing)
- João Pedro Gonçalves: *"Topic modelling for jets"*, 2018-11-01 , (ongoing)
- André Reigoto: *"Probing the Higgs Top quark couplings in ttH dileptonic events with four or more b jets at the LHC",* 2016-11-30, (ongoing)



[Structure of matter]

COMPASS
HADES
NUC-RIA

PQCD - COMPASS

Partons and QCD: Participation in the COMPASS experiments at CERN

Principal Investigator:
Catarina Quintans (100)

3 *Researcher(s):*
Celso Franco (80), Marcin Stolarski (80), Sofia Nunes (100)

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

6 *Trainee(s):*
Ana Ribeiro, Davide Giordano, Elisa Garabello, Lara Neves, Rui Gonçalves

1 *External collaborator(s):*
Nuno Teixeira

Total FTE:
4.6

Article(s) in international journals:
8 Direct contribution
Proposal(s):
1
International conference(s):
4 Oral presentation(s)
3 Proceeding(s)
National conference(s):
2 Oral presentation(s)
Seminar(s):
1 Seminar(s)

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 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.

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 the 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, using the same beam line and parts of the COMPASS spectrometer, to address important QCD-related topics.

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 function extraction.

Sources of funding

Code	Amount	Dates	Description
CERN/FIS-PAR/0007/2017	165.000 €	2017-09-01 / 2019-08-31	Collaboration in the COMPASS experiment at CERN

Total: 165.000 €

COMPASS

Lines of work and team organization

The LIP group in COMPASS follows presently four main lines of work:

- Detector Control System (DCS).
- Deep inelastic scattering studies.
- Polarised Drell-Yan studies.
- Feasibility of future QCD-related measurements at the CERN M2 beam line.

The DCS team is responsible for the development and implementation of controls and monitoring for new detectors and systems included in each year's setup. It also maintains the system permanently working (including during the winter shutdown periods). The group provides the on-call service during the approximately 7 months/year of data-taking. The team is coordinated by Christophe Pires and Ana Sofia Nunes, with support from Catarina Quintans.

An analysis of kaon, pion and proton multiplicities from deep inelastic scattering in proton unpolarised target is being performed. The data sample collected in 2016 and 2017 was processed and made available for analysis during 2018. Ana Sofia Nunes is performing the first studies on the selection of produced K^0. For charged hadrons, the multiplicities extraction is now being started by Marcin Stolarski.

The Drell-Yan data collected in 2015 were re-processed in 2018, to include several reconstruction improvements and also optimized detector calibrations and detector offline alignment. In parallel, the test processing of the 2018 data is ongoing. During the summer of 2018, a team of summer students coordinated by Catarina Quintans made comparative studies of the data quality, between 2015 and 2018 data. This fast analysis was essential to identify and correct hardware/front-end problems while the data-taking was still ongoing. Celso Franco is studying the possibility to use deep neural network methods in separating Drell-Yan and charmonium signals from background. Catarina Quintans coordinates the COMPASS Drell-Yan sub-group, participates in the drafting committee for the Letter of Intent (completed), and the Proposal (starting) of a future experiment, AMBER, dedicated to various QCD-related topics. She is also a member of the COMPASS Publication Committee, since December 2018.

Stated objectives for past year

As objectives for 2018, the LIP COMPASS group pointed the following:

- quasi-online analysis during the 2018 data-taking;
- stability studies of 2018 Drell-Yan data;
- 2016 and 2017 semi-inclusive DIS data: neutral kaons selection and identified charged hadrons selection;
- charged kaon multiplicity ratio at high momentum fraction of the virtual photon carried by the hadron, from liquid hydrogen target.
- implement the DCS developments for the 2018 run and guarantee the maintenance and on-call support during the whole data-taking period;
- participate in writing of a Letter of Intent for a future follow-up experiment to COMPASS.

Achievements and responsibilities during the past year

In 2015 COMPASS performed the first-ever dedicated polarised Drell-Yan experiment, to access the transverse momentum dependent (TMD) parton distribution functions (PDFs) of proton and pion. The analysis had strong direct contribution from the LIP team. Results, published in PRL in 2017, point to the experimental confirmation that the Sivers TMD PDF of the u-quark in the proton has opposite sign when accessed from semi-inclusive DIS (also measured in COMPASS) and from Drell-Yan. This sign change is considered a fundamental proof of the TMD approach in QCD. The low statistical significance of the observed signal motivated the 2018 run, where a factor of 1.6 more Drell-Yan events were collected.

The re-processing of 2015 data with, among other software improvements, a new beam reconstruction code, lead also to a gain of 10% statistics in the region of interest. Finally, a new method of signal from background separation based on deep neural networks is being developed at LIP. Preliminary results are showing a gain by about 15% in Drell-Yan events usable for analysis.

Two COMPASS papers were published during 2018 in which the LIP group had major responsibilities (and the corresponding author was a LIP group member):

- "Longitudinal double-spin asymmetry $A^1{}_p$ and spin dependent structure function $g^1{}_p$ of the proton at small values of x and Q^2". In this paper, non-zero spin effects are reported at low values of Bjorken-x, for the first time. A positive asymmetry is observed for the proton target, while earlier studies had shown a result compatible with zero for deuteron target. Ana Sofia Nunes is corresponding author.
- "K^- over K^+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual-photon energy". In this paper, the kaon multiplicity ratio is found to be below the lower limit expected in perturbative QCD, by a factor 2. Marcin Stolarski is corresponding author.

In what concerns the DCS system, several modifications were introduced in 2018, required by the Drell-Yan experimental setup. With respect to the previous year, some detectors were included and others excluded, and the supervisory system had to adapt to such changes. Several electronics equipments had to be replaced, due to obsolescence or to sudden failure, and the new replacing equipments integrated in the DCS. More monitoring parameters were also added, namely for beam line elements status, CEDARs parameters, polarised target parameters, additional trigger rates from scalers, and environmental radiation doses measured at specific locations of the experimental hall and surroundings. The team managed to guarantee the optimal stability and reliability of the system during the whole 2018 run.

An addendum to the COMPASS-II proposal submitted in October 2017, requesting additional data-taking in 2021 to perform a DIS measurement with transversely polarised deuteron target, was approved by the CERN Research Board on 6th June 2018. A Letter of Intent for a future multi-purpose experiment addressing fundamental QCD-related topics was prepared and released in the summer of 2018. This LoI was submitted to the CERN SPS Committee in January 2019. This document had strong direct contribution from Catarina Quintans.

In the context of the Erasmus+ European project, a cooperation agreement was signed between our LIP group and the COMPASS group from the Turin University. Two undergraduate students from Turin made two months internships at LIP in 2018, under the supervision of Catarina Quintans. These works were the basis of their "Dissertazione Tesi di Laurea", defended subsequently in Turin. This cooperation will be continued in 2019, with two other students coming to LIP for Erasmus+ internships. During the summer of 2018 the LIP group also supervised 4 portuguese undergraduate students, doing internships in "Estágios de Verão do LIP". The group plans to continue this kind of activity in 2019.

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 of the physics subgroup; control of data quality and further reconstruction improvements; preparation of the future release/publication on the differential Drell-Yan cross-section measurement; continue the development of a new method of signal from background separation based on deep neural networks.

The data collected in 2016 and 2017 by COMPASS using muon beams of both charges is being studied by LIP team members who focus on the hadron multiplicities and fragmentation functions (FFs). The processed data became available for analysis only recently, once technical problems with calibrations of different detectors were overcome. In 2016/2017, the COMPASS setup included a recoil proton detector and an upgraded RICH detector, which are essential for multiplicity studies. COMPASS has published a set of unidentified hadron, pion and kaon multiplicities extracted in a wide kinematic range from SIDIS using a LiD target, which constitute crucial input for any analysis of FFs. But larger impact can be achieved by adding the analysis of the 2016 and 2017 data collected on a liquid hydrogen target. These data are much easier to analyse from the theoretical point of view. 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 study of the charged kaon multiplicity ratio at high fraction of the virtual photon energy carried by the hadron. In order to better understand quark fragmentation in this region pbar over p ratio is now also being studied by Marcin Stolarski.

During 2019 and 2020 there is a long shutdown period at CERN, LS2. This interruption offers the timely opportunity to upgrade the DCS of COMPASS, preparing it for the 2021 data-taking period, and testing the implementation of supervision solutions for the future experiments, in line with the most up-to-date solutions used or being tested at CERN. Dedicated discussions with the CERN Industrial Controls group have started already in November 2018, in view of future close cooperation. A document with the plans for upgrade was prepared by the LIP-DCS team, which contains the details and strategy which will be followed, provided we will have enough manpower, and the means to keep a minimal workforce at CERN during the LS2 period. In this, the team is also relying on the continued COMPASS Collaboration support to these activities.

The LIP team proposed to co-organize the "XVI International Workshop on Hadron Structure and Spectroscopy - IWHSS 2019", together with the Aveiro University and I3N group in COMPASS. This proposition was accepted in March 2018, and since then the preparations have started. The workshop will take place in the Campus of University of Aveiro, from 24 to 26 June 2019.

Medium-term (3-5 years) prospects

The present scientific programme of COMPASS (CERN–SPSC–2010–01) will be completed with the 2021 run. Meanwhile, a new Letter of Intent “A New QCD facility at the M2 beam line of the CERN SPS: COMPASS++/AMBER” was recently submitted to CERN SPSC (CERN-SPSC-2019-003). This LoI will be discussed at CERN in the framework of the Physics Beyond Colliders working group and the European Strategy for High Energy Physics, due by the end of 2020.

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

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

- Participate in the writing and all the studies implied of the Scientific Proposal of COMPASS++/AMBER.

New methods of analysis are starting to be explored, which involve the use of machine learning techniques and deep neural networks to classify events as signal or background, and also for pattern recognition in RICH detector. The potential of this kind of approach is being increasingly explored in the HEP field. In COMPASS, M. Stolarski and C. Franco are presently the only researchers with expertise in this, and working on it. The group plans to invest further efforts in this field 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.

The Aveiro group collaborating in COMPASS is a strategic partner of the LIP PQCD group, and we intent to strengthen that cooperation. This group has recognized competences in Instrumentation, namely in the upgraded RICH detector of COMPASS, a detector crucial for the hadron multiplicity analyses pursued at LIP. A master thesis topic making this bridge is jointly being proposed in the Aveiro University. The two groups are co-organizing the Workshop "XVI International Workshop on Hadron Structure and Spectroscopy" (IWHSS 2019), that will take place in the Aveiro University in June 2019.

The LIP PQCD group is strongly involved in the preparation of a new fixed-target experiment at CERN, AMBER. After the COMPASS-II programme is accomplished (in 2021), there should be a smooth transition (with COMPASS++, from 2022 until the LS3 CERN shutdown) to a brand new experiment (AMBER, after LS3), in the upgraded M2 beam line. An ambitious new spectrometer is proposed. The involvement of the PQCD group will be mostly in defining the specifications needed from the physics side, by doing the necessary Monte-Carlo simulations.

The group will try to attract other researchers to join and reach a good balance between senior and junior contributors. The group is developing all efforts on this, by giving seminars in faculty departments, offering student internships during the Summer, and participating in LIP Outreach activities. The group is also participating in an ERASMUS+ exchange of students with the Turin University in Italy.

SWOT Analysis

Strengths and opportunities

The LIP group is fully integrated in the COMPASS Collaboration, taking part in the technical aspects and in physics analyses. It is also deeply involved in the scientific strategy discussions for the preparation of a future experiment on COMPASS physics and beyond. The acquired expertise in the DCS and the excellent performance and reliability of the system are well recognised by the Collaboration and also by CERN. Leading roles in coordination of physics analyses and in 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.

In 2017 the LIP group started a cooperation with the Aveiro University and I3N group in COMPASS, a group with competences in the Instrumentation area. A master thesis topic on the bridge "RICH detector performance and the physics analyses using charged particle identification from RICH" is proposed, co-supervised by Aveiro and LIP, at the University of Aveiro. A workshop is being co-organized by the two groups, the "XVI International Workshop on Hadron Structure and Spectroscopy", from 24th to 26th June 2019, followed by the COMPASS Collaboration meeting, in the Campus of Aveiro University.

In the field of controls and automation, the LIP group has been in close contact with the CERN Industrial Controls group, in view of future cooperation. The Long Shutdown at CERN provides opportunities to test new solutions and make some R&D in this field. Different options for such collaboration are being analysed. Possible collaboration of our group with the LIP Competence Center on Controls is also being discussed, although no specific action was identified yet.

In the context of the Erasmus+ European project, two undergraduate students from Turin made two months internships at LIP. During the summer of 2018 the group participanted in the LIP Summer Internships Programme. The group plans to continue this kind of activity in 2019.

Weaknesses and threats

The LIP group was reduced in terms of members in recent years, but the responsibilities taken in the COMPASS Collaboration 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. Concerning masters opportunities, we think this is partly due to the fact that none of the group members is teaching at any university. The difficulty in attracting PhD students to the project has to do with insufficient project funds to guarantee a PhD-equivalent grant while waiting for an FCT grants call. The financing obtained via the 2017-2019 CERN Fund was not enough to pay for more than 12 months post-doc, thus the project funded post-doc (A.S. Nunes) is leaving for a post-doc abroad, from February 2019.

COMPASS

Publications

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

- *"Transverse-momentum-dependent multiplicities of charged hadrons in muon-deuteron deep inelastic scattering"*, COMPASS Collaboration, Phys. Rev. D 97, 032006 (2018)
- *"New analysis of eta-pi tensor resonances measured at the COMPASS experiment"*, JPAC and COMPASS Collaborations (235 authors), Physics Letters B 779 (2018) 464–472
- *"Longitudinal double-spin asymmetry A1p and spin dependent structure function g1p of the proton at small values of x and Q2"*, M. Aghasyan et al. (COMPASS Collab.), Physics Letters B 781 (2018) 464-472
- *"Search for muoproduction of X(3872) at COMPASS and indication of a new state X^~ (3872) "*, M. Aghasyan et al. (COMPASS Collab.), Physics Letters B 783 (2018) 334–340
- *"K− over K+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual-photon energy "*, R. Akhunzyanov et al. (COMPASS Coll.), Physics Letters B 786 (2018) 390–398
- *"Light isovector resonances in π−p → π−π−π+p at 190 GeV/c "*, M. Aghasyan et al. (COMPASS Collab.), Phys. Rev. D 98, 092003 (2018)
- *"Azimuthal asymmetries of charged hadrons produced in high-energy muon scattering off longitudinally polarised deuterons"*, C. Adolph et al (COMPASS Coll.), Eur. Phys. J. C (2018) 78:952
- *"Measurement of PT-weighted Sivers asymmetries in leptoproduction of hadrons"*, M.G. Alexeev et al (COMPASS Coll.), Nucl. Phys. B 940 (2019) 34–53

3 International Conference Proceedings

- *"Final COMPASS results on hadrons, pions and kaons multiplicities in SIDIS"*, Marcin Stolarski on behalf of the COMPASS Coll., PoS DIS2017 (2018) 235
- *"Polarised Drell-Yan results from COMPASS"*, C. Franco on behalf of the COMPASS Coll., arXiv:1804.09516 [hep-ex]
- *"K- over K+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual-photon energy"*, A.S. Nunes on behalf of the COMPASS Coll., PoS(DIS2018)018

1 Proposals

- *"COMPASS++/AMBER: A new QCD Facility at the M2 beam line of the CERN SPS"*, B. Adams et al., Letter of Intent, arXiv:1808.00848, CERN-SPSC-2019-003 (SPSC-I-250)

Presentations

4 Oral presentations in international conferences

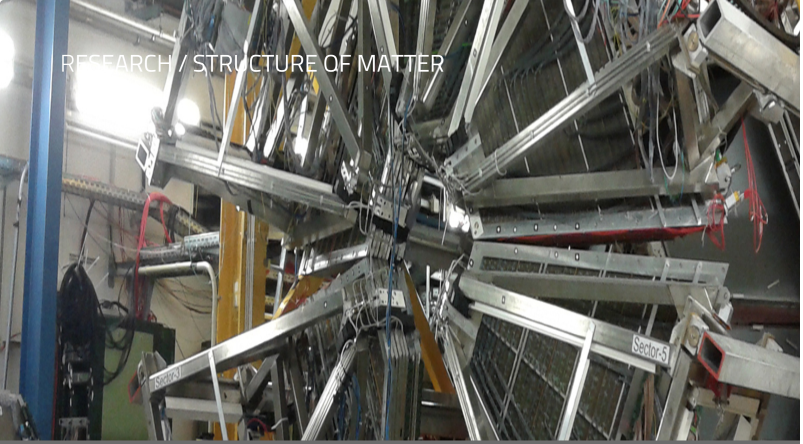
- Marcin Stolarski: *"COMPASS results on kaon multiplicities"*, 2018-02-20, Workshop on Fragmentation Functions FF 2018, Stresa, Italy
- Catarina Quintans: *"Future Drell-Yan @ COMPASS and elsewhere"*, 2018-03-20, IWHSS 2018, XIIV International Workshop on Hadron Structure and Spectroscopy, Bonn, Germany
- Celso Franco: *"Polarised Drell-Yan results from COMPASS "*, 2018-03-23, Hadron Physics 2018 – 14th International Workshop on Hadron Physics, Florianópolis, Brazil
- Sofia Nunes: *"K− over K+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual-photon energy"*, 2018-04-19, XXVI International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2018), Kobe, Japan

2 Presentations in national conferences

- Sofia Nunes: *"Partons and QCD from COMPASS at LIP"*, 2018-02-16, Jornadas LIP 2018, Évora, Portugal
- Christophe Pires: *"COMPASS Detector Control System"*, 2018-02-16, Jornadas LIP 2018, Évora, Portugal

1 Seminars

- Catarina Quintans: *"Partons and QCD at COMPASS"*, 2018-05-09, FCUL, Lisbon, Portugal



HADES

Collaboration in the HADES experiment at GSI

Principal Investigator:
Alberto Blanco (15)

3 *Researcher(s):*
Celso Franco (5), Luís Pereira (8), Paulo Fonte (5)

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

Total FTE:
0.5

Article(s) in international journals:
3 Indirect contribution

International conference(s):
1 Oral presentation(s)

International meeting(s):
1 Oral presentation(s)

National conference(s):
1 Oral presentation(s)

Collaboration meeting(s):
1 Oral presentation(s)

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. In recent years, the group was complemented with the incorporation of people from the LIP-COMPASS group who assumed tasks on the physics analysis. Currently the group has assumed new commitments with the construction of a new TOF detector for the HADES forward region, the RPC-TOF-FD, and reinforced our position by collaborating with the Multi Drift Chamber (MDC) group.

The accelerator infrastructure at GSI was shutdown during the last five years and resumed in mid 2018. The upgraded HADES spectrometer, with a new electromagnetic calorimeter (ECAL) and a new RICH detector, has already accomplished an engineering run at the end of 2018, and is ready for production beam time in 2019. The performed upgrades will put into operation the future SIS100 synchrotron at the new FAIR facility, providing higher beam energies and intensities. 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, whose theoretical work is of special interest for HADES. The project was not recommend for funding.

Sources of funding

Code	Amount	Dates	Description
000-HADES	10.000 €	2015-02-01 / 9999-12-31	HADES generic funding

Total: 10.000 €

HADES

Lines of work and team organization

There are two main lines of work, one related to hardware and the other related to physics analysis:

Hardware

- **RPC-TOF-W operation:** Operation of the RPC-TOF-W 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, C. Franco, 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.

Physics analysis

- **Dilepton analysis:** One of the major goals of HADES is the investigation of hadron properties inside a baryon-rich medium. According to the Chiral Mean Field model the baryonic densities achieved at HADES, with low energy heavy ion collisions (1-2 AGeV), are high enough to produce a state of matter resembling matter resulting from the collision of two neutron stars. Besides the astrophysical relevance, this investigation is a unique contribution to the study of phase transitions in QCD matter: HADES is the only running experiment exploring the phase space at high densities (3 times the normal density) and moderate temperatures (70-80 MeV). The high barionic density achieved in a heavy-ion collision at HADES is enough to partially melt the quark-antiquark condensates that are responsible for the chiral-symmetry breaking in hadrons. Since these condensates are thought to be the main contributors to the hadronic masses, a detailed investigation of the hadronic properties inside the "fireball" (dense medium created by the heavy-ion collision) can provide a clearer picture about the mechanism responsible for the mass generation in hadrons. The fireballs of HADES are long-lived (up to a factor of 3 longer than the pion-rich fireballs produced at higher energy collisions) and can be cleanly investigated through the detection of dileptons coming from the decays of short-lived hadrons. Since these dileptons do not interact strongly within the fireball, they can be used as clean probes of the hadronic properties inside the dense medium. The LIP-group collaborates in all the investigations of the HADES dilepton group. Responsibility: C. Franco.

The LIP team is represented by the PI of the project (A. Blanco) in the HADES Technical Board and in the HADES Collaboration Board.

Stated objectives for past year

- Re-installation of the RPC-TOF-W in the new ECAL main frame. The RPC together with all subsystems and cabling will be reinstalled, which is a major operation.
- Prepare the RPC-TOF-W for the run Ag+Ag @ 1.75 AGeV in the second half of 2018.
- Implementation of the RPC-TOF-FD in the software of the experiment.
- Construction and evaluation of the first prototype of RPC-TOF-FD. After validation, four modules will be constructed and integrated into the HADES spectrometer by the end of the year.
- Assembling an evaluation of the MDC prototype Lenav2. Run with aged MDC chambers with water over four weeks at highest beam intensity to approve its stability in the current and future higher beam intensities at FAIR. Most important, prepare the rebuild of plane II within a collaboration of labs, namely: LIP, GSI, HZDR and JINR Dubna.
- Analysis of the data gathered in Ag+Ag collisions at 1.75 AGeV using the dilepton channel.
- Preparation of the HADES Physics program for FAIR with the development of a NLO J/ψ simulation for p+p and p+Au systems.

Achievements and responsibilities during the past year

Due to a serious incident during the start up of the accelerator infrastructure, the Ag+Ag run scheduled for the second half of 2018 was shifted to first half of 2019. In addition, all the scheduled program for 2019 (beam time with pions and protons) is shifted to 2020 and, therefore, no more beam is available in 2019 after the Ag+Ag run. This caused a delay in our plans, as explained below.

The re-installation of the RPC-TOF-W (together with all subsystems and cabling) in the main frame of the new ECAL detector, a major operation, was accomplished successfully. An engineering run at the end of 2018 demonstrated that the detector is exactly with the same performance as before, being ready for the Ag + Ag production beam time in the first half of 2019.

The implementation of the RPC-TOF-FD in the software of the experiment had little progress. The main reason for that is the lack of manpower available within the group. We tried by incorporating a new member Luis Pereira, but it was not possible to secure him due to the lack of financial resources, leaving the group without finalizing the implementation.

A prototype module of RPC-TOF-FD was designed and built in close collaboration with the Detector Laboratory (DL) and the Mechanical workshop (MW) (this is a task shared also with the SHIP and RPC R&D groups). After validation with cosmic rays in the Coimbra DL, the prototype was exposed to negative pions of -8 GeV in October 2018 at CERN T9 test beam area. The response of the systems was tested with the help of four timing scintillators with a timing accuracy of 30 ps sigma, used as a reference. The almost 2 m² active area was scanned on different positions in order to obtain efficiency and timing accuracy. The results show an average efficiency and timing accuracy of 98% and 54 ps without noticeable dependence with position over the entire area. The construction of the final detector, composed by four modules, is delayed due to the delay in the HADES program.

In collaboration with the HADES MDC group, the MDC prototype Lenav2 was designed and assembled in order to explore the lower limits of the drift cell size. Preliminary test showed a reasonable gas-tightness, electrostatic stability was also achieved, but gas amplification causes HV instability, to be further explore. Aged MDC chambers were run with water over four weeks at highest beam intensity to approve its stability in the current and future higher beam intensities at FAIR. The rebuilt of MDC plane II was postponed due to more urgent activities within the group.

Results of the Au+Au beam time were reported in the conference Kruger2018. Due to the shift in time of the Ag+Ag run, no data was available for analysis and this task was postponed to 2019 together with the preparation of the HADES Physics program for FAIR.

Lines of work and objectives for next year

- Finalize the analysis of the 2018 test beam data, present results to the collaboration and prepare a paper for regular publication.
- Finalize the implementation of the RPC-TOF-FD in the official software of the experiment. This task will be accomplished by C. Franco, which gives us guarantees of its completion within the year.
- 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.
- Start the analysis of the dilepton data that HADES will collect this year using Ag+Ag at 1.75 AGeV. The goal is to continue the study of the onset of chiral symmetry restoration in a baryon rich medium. The Ag+Ag data will be extremely important for the study of the mass generation mechanism in hadrons since it will allow to access, for the first time at low energies, to the intermediate mass region of the dilepton mass spectrum (above 1 GeV). Therefore, it will become possible to study the in-medium correlations between the vector meson r and the axial vector meson a1. Both spectral functions are needed to estimate the in-medium depletion of the chiral condensates.
- Continuation of the activities in order to attract students/researchers to the group; otherwise the activities proposed will be severely affected. A symposium on the HADES Physics is being organised this year. The goal is to join some researchers (working in Portugal) with competences in the field, one expert from GSI and several students.
- 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 upgrade. Integration of the new fee in the HADES main CAD, to check for possible constrains. Monitoring chambers performance during the next beam time.
- A new funding request opportunity will be available this year, PTDC 2019. A proposal will be prepared.

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. It should be noted that the experiment will resume its regular data taking this spring after a hiatus of 5 years to upgrade the GSI accelerator infrastructure. Therefore, the group expects to substantially increase the number of FTEs dedicated to the HADES activities. For this to happen it is crucial to attract at least 1 student to the group and one more researcher. Without this extra man power the analysis activities of the group will be strongly compromised. The group would need a funding of 200 k€ for a period of 3 years to face, in an efficient way, all the challenges ahead (for hardware development and to pay for human resources). The plan for the next 5 years is the following:

- On the hardware side the group will prepare and operate for production beam times the RPC TOF (producing the calibration parameter) and is constructing a new RPC detector to cover the acceptance at low polar angles in the forward region. This detector, which uses a novel concept for the construction of the RPC gaps, will show a high timing resolution, < 70 ps , below the requirement (100 ps), and efficiency> 99% for Minimum Ionizing Particles (MIPs) in combination with large area, low gas consumption (environmentally friendly) and low cost. Qualities that fit perfectly the requirements of TOF-FD. Once the expectations of this technology are demonstrated, this will open the opportunity to implement this technology in other High Energy Physics experiments, e.g. the SHiP experiment at CERN where high performing timing detectors implemented in large areas at low cost are mandatory.

- In addition, the group will collaborate with the tracking group in order to prepare/optimize the existing tracking system for the incoming data taking periods.
- On the analysis side, as stated above, it is extremely important to attract students/researchers to the group; otherwise the activities proposed below will be severely affected. In order to overcome the lack of manpower a symposium on the HADES Physics is being organised this year. The goal is to join some researchers (working in Portugal) with competences in the field, one expert from GSI and several students. The idea is to attract at least one student to the group.
- The research plan is to analyse the dilepton data that HADES will collect this year using Ag+Ag at 1.75 AGeV. The goal is to continue the study of the onset of chiral symmetry restoration in a baryon rich medium. The Ag+Ag data will be extremely important for the study of the mass generation mechanism in hadrons since it will allow to access, for the first time at low energies, to the intermediate mass region of the dilepton mass spectrum (above 1 GeV). Therefore, it will become possible to study the in-medium correlations between the vector meson r and the axial vector meson a1. Both spectral functions are needed to estimate the in-medium depletion of the chiral condensates.
- In 2020 HADES will take data with a pion beam impinging in a polyethylene/carbon target. Emphasis is on the electromagnetic structure of baryons and the role of intermediate r mesons as doorway states in the decay process. The measurement of dilepton production off the nucleon is sensitive to the electromagnetic transition form factors of baryons and probes the role of vector mesons. Differential cross sections for hadronic final states will also be used to extract various baryon-meson couplings, among which are the rN. Since the r meson plays an important role in the dilepton data from heavy ion collisions, the analysis of the pion beam data is of crucial importance to understand the mass generation mechanism in hadrons (to provide a reference for the in-medium spectral function of the r). This work can be done by a student wanting to join the group.
- A possible collaboration with the group of Constança Providência, in order to bridge the HADES data and the theoretical models about neutron star mergers, will be pursue, possibly with the incorporation of a student as task force.
- The group is also preparing the future migration of HADES to FAIR. On the hardware side the group is collaborating in 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. On the analysis side the group will contribute to the development of some Physics simulations (in particular, the development of a new J/y generator for a p+Au run)

SWOT Analysis

Strengths

- 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.
- At the moment the group has strong competences in machine learning algorithms and in simulations and, on the physics side, in both particle and nuclear physics (processes involving leptonic, hadronic or heavy-ion collisions), which certainly adds value to the scientific projects of HADES at FAIR.

Opportunities

- 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.
- One of the team members was responsible for one of the independent analysis of the main physics goal of HADES (using the Au+Au data). The acquired know-how will facilitate a possible integration of a student in the analysis activities. The experiment is about to start its first phase-0 run at FAIR and, therefore, it is the ideal time to integrate a student in the analysis group.

Weaknesses

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

Threats

- The lack of funding may strongly compromise all the group activities

HADES

Presentations

1 Oral presentations in international conferences

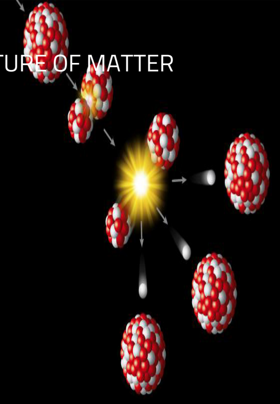
- Celso Franco: ***"Heavy-ion results from the HADES experiment"***, 2018-12-03, Kruger2018 Discovery Physics at the LHC, Casa do Sol, Johannesburg, South Africa

1 Oral presentations in international meetings

- Alberto Blanco: ***"Participation in the HADES experiment"***, 2018-05-04, First joint Workshop IGFAE / LIP, Braga

1 Presentations in national conferences

- Celso Franco: ***"Exploring dense matter with dielectron probes at HADES"***, 2018-01-16, Jornadas do LIP 2018, Évora, Portugal



NUC-RIA

Experimental Nuclear Astrophysics

Principal Investigator:
Daniel Galaviz (50)

3 *PhD Student(s):*
Elisabet Galiana (100), Pamela Teubig (40), Paulo Velho (50)

2 *Master Student(s):*
Francisco Barba (16), Ricardo Honorio (50)

4 *Trainee(s):*
Andriy Myakush, Beatriz Pinheiro Pereira, Francisco Matias, Rita Silva

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

Total FTE:
3.1

Article(s) in international journals: **1** Direct contribution, **4** Indirect contribution

Executive summary

The efforts of the research group were shared between the two main research lines we have pursued over the past years:

Concerning the participation in the R^3B collaboration at FAIR, the first series of experiments, expected in the fall of 2018, were delayed to the beginning of 2019, due to technical problems affecting the FAIR laboratory infrastructure. Besides the instrumentation work, the group has contributed to the development of software simulation and analysis tools for the CALIFA calorimeter. In 2019 the work within the R^3B collaboration will continue. We are directly involved in two experimental proposals using the new experimental devices during 2019, continuing the efforts in the study of breakup reactions on halo nuclei. Furthermore, in collaboration with IGFAE in USC, additional test experiments using CALIFA modules are foreseen during 2019 in Lisbon within the framework of the PhD Thesis of Elisabet Galiana, who joined the team in 2018.

The line of work foreseen at ISOLDE/CERN reached remarkable achievements during 2018 and has as well an exciting year ahead in 2019. As the laboratory was not accepting new proposals during the second half of 2018 (due to the large number of hours already approved), and considering the upcoming LS2 at CERN, the study of nuclear reactions in inverse kinematics planned in the letter of intent submitted last year was redirected towards a stable beam facility, specifically LNS-INFN in Catania, Italy. Together with colleagues from that laboratory and in the framework of an international collaboration, the group submitted a scientific proposal to study the scattering of nickel isotopes on a helium target in inverse kinematics. The proposal was positively evaluated by the scientific committee of the laboratory, being recommended for beam time with the highest priority. We expect to run the experiment during 2019.

The project submitted within the Portugal2020 framework last year was not recommended for funding. The group has however joined an international consortium and applied for funds for the development of large area dosimetry devices monitoring the irradiation of fresh fruits with electron and photon beams. The resolution of this application should be known by the beginning of 2019.

Sources of funding

Code	Amount	Dates	Description
CERN/FIS-PAR/0005/2017	24.640 €	2018-07-01 / 2020-02-29	PORTUGAL at ISOLDE

Total: 24.640 €

NUC-RIA

Lines of work and team organization

The group maintains the structure of the previous years, with Daniel Galaviz as main researcher and without presently additional researchers with a PhD. The four topics which define the lines of work carried out by the group are still:

- High-energy reactions and data analysis on exotic nuclei at GSI/FAIR.
- Instrumentation for upcoming experiments at R^3B/FAIR.
- Low-energy reactions on stable and unstable nuclei for nuclear astrophysics.
- Technology transfer, namely contributions to the study of electron beam food irradiation.

During 2018, Elisabet Galiana, a PhD student at the University of Santiago de Compostela joined the group. Also the Physics Engineering Master student Francisco Barba joined the group. During 2019 we will seek for candidates to start a PhD program on the data taken from the measurements done at FAIR.

Stated objectives for past year

- Participation in R^3B Day-Zero experiments in 2018.
- Conclusion of the analysis of CALIFA benchmark experiment at Lisbon.
- Reinforcement of the LIP participation at ISOLDE/CERN.
- Development of applications using the GEANT4 simulation framework (after the arrival of Elisabet Galiana)
- Increase the activity related to the modelling of the dose distribution in fresh fruits when treated with electron and photon beams from accelerators.

Achievements and responsibilities during the past year

We would like to highlight the following achievements during 2018:

Preparations for Day-Zero experiments at FAIR: the preparations for the FAIR experiment S444, experiment planned to benchmark the new detection systems of the R3B experiment, started during the spring of 2018. Our team joined these efforts on-site contributing to the test and verification of previously developed analysis tools for the CALIFA calorimeter. Three members of the team participated in this phase at GSI.

Analysis of CALIFA benchmark experiment in Lisbon: two CALIFA petals, with a total of 124 individual CsI(Tl) crystals, were exposed to photons with energies higher than 12 MeV. The large amount of data obtained at various energies has allowed a precise determination of the topology of gamma events at various energies. This information will be very relevant for the analysis of data obtained from reactions on radioactive beams at FAIR. The publication of the results is underway.

Approved proposal at LNS-INFN laboratory: the line of work foreseen for the ISOLDE/CERN laboratory using radioactive beams was redirected and complemented with a proposal for the measurement of the elastic scattering of alpha particles on heavy stable isotopes in inverse kinematics at the Tandem Accelerator of the LNS-INFN laboratory in Catania. The experimental proposal, led by our group, was approved by the Proposal Advisory Committee of the LNS laboratory with the highest priority to run during 2019. This experiment will be part of the master thesis work of the student Francisco Barba, who joined the team in 2018.

Participation in IS616 experiment at ISOLDE/CERN: the activity of the group around the ISOLDE laboratory was complemented with the participation of the team leader in experiment IS616, focused on the study of the elastic scattering of ^{8}B on ^{64}Zn at energies close to the Coulomb barrier. In addition to strengthen the collaboration with the reaction line we foresee to use in the future at this laboratory, it settled the basis for the presentation of the proposal at LNS.

Development of natural gamma background generators: using the EnsarRoot simulation framework, event generators for the different photons emitted during the decay of radioactive isotopes commonly found in nature (^{238}U, ^{232}Th, ^{235}U and ^{40}K) were developed for a precise determination and characterization of the natural background registered on different laboratories using a Hiper Pure Germanium (HPGe) detector. The analysis of the data using the complete response of the detector allows the analysis of the individual components, including the contribution of cosmic rays. In collaboration with laboratories in different locations in Portugal, the time evolution of the different components of the spectrum will be as well evaluated during 2019.

Lines of work and objectives for next year

2019 is full of challenges and activity for the NUC-RIA group. The main lines of work the group aims to cover are:

- Participation at R^3B Day-Zero experiments: The Day-Zero experiments planned at FAIR for the fall of 2018 will finally take place during the first 4 months on 2019. The group plans to contribute to the experiment S444, benchmark experiment of the R3B collaboration, in which a large part of the CALIFA electromagnetic calorimeter will be exposed to the detection of photons emitted by nuclei at relativistic energies and high energy protons from reactions in inverse kinematics.

- Alpha elastic scattering in inverse kinematics at LNS: The proposed and approved experiment to measure the elastic scattering of nickel isotopes on ^{4}He nuclei in inverse kinematics will be prepared and executed during 2019. 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.
- Preparation and execution of S442: The team was an active partner in a scientific proposal submitted to the FAIR Advisory Committee, on the study of “multi neutron configurations in atomic nuclei towards the drip line”. We are committed to actively participate in this experiment, both execution and data analysis. However, due to the delay experienced by the Day-Zero experiments (originally scheduled for 2018), this experiment may not run during 2019. The group will seek for candidates to analyze the data in the framework of a PhD program.
- CALIFA tests at CTN: based on the success of the 2016 run, and in the framework of the PhD Thesis of Elisabet Galiana, we plan to run additional measurements of high-energy photons using modules of the CALIFA calorimeter from the IGFAE group in USC. In this case, high-energy states in argon isotopes will be populated by low-energy protons interacting on chlorine targets, done as well locally by our group using the thermal evaporator device at the Faculty of Sciences (FCUL).
- National grant application for ISOLDE/CERN: the group will continue to be part of the national consortium around the ISOLDE facility at CERN. This time, we will strengthen the nuclear reaction line, reinforced by the complementary experiments approved at the LNS laboratory. This continuation will create the basis for the proposal of experiments after LS2 at the HIE-ISOLDE facility, studying for the first time the interaction of unstable nuclei with alpha particles at energies of astrophysical interest.
- Participation in the ERINS consortium: Following the participation of the group in the ENSAR and ENSAR2 (European Nuclear Structure and Application Research) consortia, LIP will enter as beneficiary in the application (presently under preparation) to the European Research Infrastructure call of 2019, as part of the so-called ERINS (European Research Infrastructures for Nuclear Science). In addition to benefiting from available funds for Transnational Access to the research infrastructures of the consortium, the group will participate in a joint research action devoted to the use of artificial neural networks for the analysis of nuclear data with large area and granularity detection systems.

Medium-term (3-5 years) prospects

The 5-year period 2019–2024 opens a time full of challenges aligned with the activity of the group in the two international installations we have been working in over the past years. Here we provide some insights on the specific activities foreseen on each of the facilities and research lines:

FAIR/R3B

- Day-Zero @ FAIR: The first Day-Zero experiments at FAIR start 2019. We are involved, within the R3B collaboration, in the preparation and execution of the first benchmark experiments of the setup, with special focus on the electromagnetic calorimeter CALIFA.
- Experiment S442: We were proponents of experiment S442, devoted to the study of multi-neutron configurations towards the drip-line, and in which it will be possible to continue the study of neutron knock-out reactions on halo nuclei, in particular ^{14}B and ^{17}C.
- High-energy photon detection with CALIFA: In collaboration with IGFAE at USC, we plan to execute at the CTN/Lisbon laboratory an additional experiment exposing CALIFA calorimeter modules to high energy photons, within the framework of the PhD Thesis of Elisabet Galiana.

ISOLDE/CERN and LNS-INFN

In close collaboration with Spanish and Italian groups, we lead an international collaboration developing research around the use of newly developed ^{4}He solid targets.

- LNS-INFN: The experimental proposal *INVERSE-ALPHA*, lead by our group, was submitted to the LNS-INFN Proposal Advisory Committee (PAC) and recommended, with the highest priority, to run during 2019. This experiment opens a line of research we aim to continue over the next 2-3 years, performing reactions on stable heavy isotope beams at low energies on ^{4}He solid targets in inverse kinematics. This first experiment will be part of the master thesis of Francisco Barba, at FCUL.
- HIE-ISOLDE/CERN: After closing LS2 at CERN, in 2021, and based on the results obtained at the stable beam facility LNS-INFN, we plan to propose similar experiments using radioactive beams at the HIE-ISOLDE/CERN facility, exploring for the first time fundamental properties of radioactive nuclei relevant in astrophysical environments. This would solidly base a second pillar for fundamental research, in this case in the field of nuclear astrophysics.

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 2020. Its renewal during 2019 (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 is under threat.

Publications

1 Articles in international journals

(with direct contribution from the team)

- *"Structure of Be-13 studied in proton knockout from B-14"*, G. Ribeiro, E. Nacher, O. Tengblad, et al., Phys. Rev. C 98, 024603 (2018)

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

[Cosmic ray]

AMS
Auger
LATTES

AMS

Collaboration in AMS - Alpha Magnetic Spectrometer

Principal Investigator:
Fernando Barão (60)

3 ***Researcher(s):***
Luisa Arruda (20), Paula Bordalo (75), Sérgio Ramos (75)

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

4 ***Trainee(s):***
Beatriz Bordadágua, Clara Severino, J. B. Lousada, J. L. Figueiredo

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

Total FTE:
3.3

Article(s) in international journals:
2 Direct contribution
3 Indirect contribution
International conference(s):
1 Oral presentation(s)
1 Poster(s)
1 Proceeding(s)
National conference(s):
2 Oral presentation(s)
Collaboration meeting(s):
1 Oral presentation(s)
Seminar(s):
2 Seminar(s)
2 Outreach seminar(s)

Executive summary

Since 1998 LIP is part of the broad international collaboration that designed and operates the Alpha Magnetic Spectrometer (AMS). The project had two distinct phases: a prototype was built and flown aboard the space shuttle in 1998, and the 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 130 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.

Since the launch of AMS in 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.

Sources of funding

Code	Amount	Dates	Description
CERN/FIS-PAR/0020/2017	35.000 €	2017-09-01 / 2019-09-01	Collaboration in AMS - Alpha Magnetic Spectrometer

Total: 35.000 €

AMS

Lines of work and team organization

The main activities in which 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 particle charge sign. Since 2011 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 boosted decision trees (BDT) or probability density function (PDF) techniques. Such tools can be used on anti-proton/electron separation and on isotope identification.

Observations of light isotopes provides information on the origin of cosmic rays and propagation in the galaxy. The study of unstable isotopes, like ^{10}Be, is essential to disentangle the size of the galaxy halo from the diffusion coefficient, translating the strength of the diffusion process cosmic rays undergo. These are two key parameters of cosmic rays propagation. Some isotopes are of primary origin while others are produced by collisions of cosmic primaries with the interstellar matter.

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 2018 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, electrons, ...)
    - nuclei selection and isotopic studies

Achievements and responsibilities during the past year

The group (Fernando Barão and Miguel Orcinha) participated in the monitoring operation at CERN.

During the last year, low-energy cosmic ray physics and solar modulation were the main focus of the group.

Concerning AMS measurements, the work being done on the time dependent proton flux was continued and the work in progress was presented and discussed in an AMS General Analysis Meeting. This flux is calculated using an analysis framework developed by this group and is significantly sped up by using reduced data "ROOT trees" produced by Laurent Derome, also a member of the collaboration and 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, several works were produced and articles published interpreting cosmic ray data from several experiments (including AMS) and studying the correlation (and time delay) between the solar activity cycle and the temporal variability of the cosmic ray flux. This work generated an article, in the end of 2017, in The Astrophysical Journal Letters which was later chosen by the American Astronomical Society as an article of great relevance and on which it wrote a review article for the Research Highlights from the journals of the American Astronomical Society.

Another product of this fruitful collaboration, developed with the help of two IST graduate students (J. L. Figueiredo, J. B. Lousada) in the context the LIP/LabRC internship program, was the interpretation of recent AMS results on the proton flux in order to test and understand the diffusive transport mechanism that cosmic rays go through before they reach Earth. This work was then reliant on the resolution of Parker's cosmic ray transport equation (the basis of solar modulation) in a 1-dimensional finite-difference scheme developed by these two students and resulted in another article which is already published in Physical Review Letters.

These works were presented in AMS Analysis General Meetings and on several international conferences pertaining to cosmic ray Physics. The most recent contribution was made by Miguel Orcinha in the "26th Extended European Cosmic Ray Symposium and 35th Russian Cosmic Ray Conference" in Barnaul, Russia, where he presented both the results of the first article mentioned in this text and a poster on the recently published AMS proton, helium, electron and positron fluxes, on behalf of the collaboration.

As mentioned before, the group was part of LIP's scientific summer internships, contributing with several themes and supervising five students. Fernando Barão was responsible for the planning of three topics ("Development of a display of muon rates", "Solar Modulation in AMS" and "Particle identification in SNO+: development of a numerical tool") and the supervision of the five students participating in them.

Lines of work and objectives for next year

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

The LIP team members will participate in the AMS mission control activities, performing shifts and acting as on-call experts for the RICH subdetector. LIP shifters are also 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. When acting as on-call experts, they are responsible for reporting the RICH detector's behaviour to the collaboration in its daily briefings and performing contingency procedures if any issues occur with the RICH. 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 6-10 days every 2 months.

Variability studies of proton fluxes at low energy and their interpretation under Solar modulation models

By making use of AMS' large exposure time and measurement precision, several studies will be performed in order to fully characterize the solar modulation phenomenon. The different temporal structures in solar modulation will also be studied by making use of the high temporal resolution available in AMS-02 data. Solar modulation also presents a charge sign dependency that should be studied as it is essential towards the comprehension of most of its different aspects.

This topic will involve the following steps:

- Finalizing the estimation of the proton flux with the updated AMS tracker algorithm
- Temporal variability study of cosmic ray fluxes (frequency analysis, time correlation with solar events)
- Usage of the propagation platform developed for the time-delay analysis of the time dependent proton flux
- Development and improvement of data analysis platform focused on systematic estimation, flux unfolding techniques and inclusion of additional particle selections (positron, anti-proton, helium and electrons)
- Charge sign effect on cosmic ray flux

Light isotope nuclei identification

Light isotopes like H and ^{4}He (and CNO) are believed to be of primary origin. Rarer cosmic ray elements such as ^{2}H, ^{3}He (and Li-Be-B) are believed to be of secondary origin, i.e. produced by collisions of primary cosmic rays with the gas nuclei of the interstellar medium (ISM). The secondary cosmic ray fluxes 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., ^{10}Be/^{9}Be) will allow to estimate the halo size and the cosmic ray galactic confinement time (diffusion).

The AMS isotope analysis aims at measuring the fraction of isotopes that can be found on cosmic rays for different elements like Helium (^{3}He, ^{4}He) – primordial, and Lithium (^{7}Li, ^{6}Li) and Beryllium (^{10}Be, ^{9}Be) – of secondary origin. Isotope identification requires a detector that can provide a good mass separation. The ability to separate masses relies on a good measurement of both velocity and momentum. In AMS, particle momentum is measured with a resolution of ~10 % up to ~ 20 GV, degrading a bit at very low momenta due to multiple scattering. While particle velocity is measured (RICH) with a 0.1 % precision for Z=1 particles. Given such resolutions, in order to explore a domain of energy as large as possible in isotope identification, it is necessary to develop mass template fit methods.

RICH performance

The knowledge of heavy nuclei fluxes provides valuable information on the primary sources of cosmic rays and propagation parameters. For instance, the diffusive halo height is a key ingredient in the prediction of dark matter induced fluxes. As AMS gathers more events, these lower fluxes are now able to be estimated with meaningful statistics and accuracy.

The main challenge with selecting heavier nuclei comes from their non-negligible probability of fragmentation inside the detector, creating a very particular pattern of events which are constituted by lower charged particles and often disregarded. Including these events would generate a better accuracy.

The group intends to develop a selection framework for heavier nuclei in order to estimate their rates and study their interactions with the detector. These events will also be used to study the RICH detector.

Following the work the group has done on the subdetector RICH and the extensive knowledge collected over the years, the group will continue its involvement by studying performance as a function of time, both on velocity and charge reconstruction. The RICH was built to provide AMS with the most precise velocity measurement and, concerning the LIP algorithm, it is the team’s responsibility to guarantee it.

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** (estimated to be in October 2013) and will continue to be operational during the next reversal (estimated to be in 2024), thus observing with great detail more than one total solar activity cycle. 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. The different periodicities can be extracted from the cosmic ray data and then correlated to the different solar parameters (magnetic field intensity, tilt angle, solar wind speed, number of sunspots, etc.) in order to better understand the highly conductive plasma emanating from the sun and the diffusive propagation of cosmic rays in it.

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 interest 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.

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, operating systems and programming/scripting languages. It has experience in numerical resolution of physical problems.

It developed in collaboration with another laboratory a very well sedimented analysis framework with high capability 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

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

- *"Observation of Fine Time Structures in the Cosmic Proton and Helium Fluxes with the Alpha Magnetic Spectrometer on the International Space Station"*, AMS Collaboration, Phys. Rev. Lett. 121, 051101
- *"Testing Diffusion of Cosmic Rays in the Heliosphere with Proton and Helium Data from AMS"*, N. Tomassetti, F. Barão, B. Bertucci, E. Fiandrini, J. L. Figueiredo, J. B. Lousada, and M. Orcinha, Phys. Rev. Lett. 121, 251104

1 International Conference Proceedings

- *"Observation of a time lag in solar modulation of cosmic rays in the heliosphere"*, M. Orcinha, N. Tomassetti, F. Barão and B. Bertucci, Proceedings, 26th Extended European Cosmic Ray Symposium and 35th Russian Cosmic Ray Conference, Barnaul - Belokurikha - Altai Mountains, Russia

Presentations

1 Oral presentations in international conferences

- Miguel Orcinha: *"Observation of a time lag in solar modulation of cosmic rays in the heliosphere"*, 2018-07-07, 26th Extended European Cosmic Ray Symposium and 35th Russian Cosmic Ray Conference, Barnaul - Belokurikha - Altai Mountains, Russia

1 Poster presentations in international conferences

- Miguel Orcinha: *"Precision Measurement of the Monthly Cosmic Ray Fluxes with the Alpha Magnetic Spectrometer on the ISS"*, 2018-07-07, 26th Extended European Cosmic Ray Symposium and 35th Russian Cosmic Ray Conference, Barnaul - Belokurikha - Altai Mountains, Russia

2 Presentations in national conferences

- Fernando Barão: *"Raios Cósmicos: cem anos a sondar o Universo..."*, 2018-08-30, FÍSICA2018 – 21ª Conferência Nacional de Física e 28º Encontro Ibérico para o Ensino da Física, Covilhã, Portugal
- Fernando Barão: *"Medida da aceleração da gravidade com um pêndulo gravítico e um microcomputador RPI"*, 2018-08-30, FÍSICA 2018 - 21ª Conferência Nacional de Física e 28º Encontro Ibérico para o Ensino da Física, Covilhã, Portugal

2 Seminars

- Miguel Orcinha: *"Parallel Selection of Protons in AMS - Optimizing data selection with Open MPI"*, 2018-12-14, Seminar for the course of “Programming for Cluster and Multicore”, taught by Alcides Fonseca, for the MSc in Computer Science of the Faculty of Sci- ences of the University of LisbonFaculdade de Ciências da Universidade de Lisboa, Lisboa, Portugal
- Miguel Orcinha: *"Parallelization of Code in Physics - An introduction to Parallelization & MPI"*, 2018-12-20, Seminar for the course of “Computational Physics”, taught by Fernando Barão, for the MSc in Physics Engineering of Instituto Superior TécnicoInstituto Superior Técnico, Lisboa, Portugal

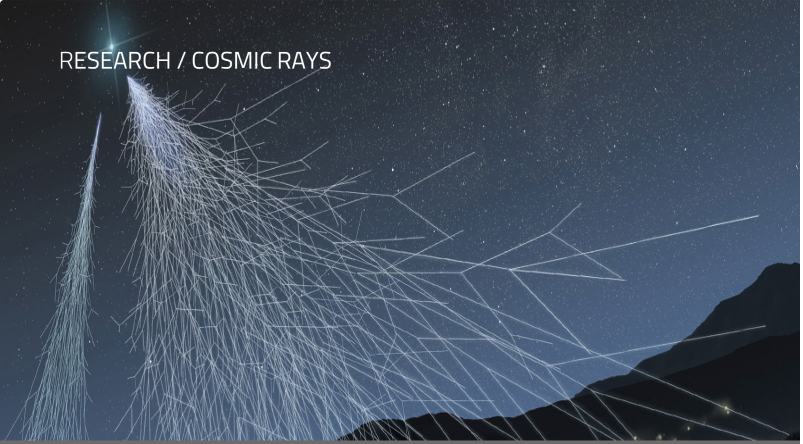
2 Outreach seminars

- Miguel Orcinha: *"LIP - Das profundezas da terra ao espaço (The AMS Experiment)"*, 2018-05-09, 32º aniversário do LIPLaboratório de Instrumen- tação e Física Experimental de Partículas, Lisboa, Portugal
- Fernando Barão: *"Observar é medir"*, 2018-12-07, Seminar for high-school students at LIPLIP-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

Principal Investigator:
Pedro Assis (85)

16 *Researcher(s):*
Alberto Blanco (25), Alessandro de Angelis (5), Bernardo Tomé (50), Catarina Espírito Santo (35), Felix Riehn (96), Francisco Diogo (32), Helmut Wolters (20), Liliana Apolinário (15), Lorenzo Cazon (100), Mário Pimenta (48), Patrícia Gonçalves (20), Paulo Fonte (10), Pedro Abreu (55), Raul Sarmento (100), Ruben Conceição (50), Sofia Andringa (50)

7 *Technician(s):*
Américo Pereira (10), José Carlos Nogueira (90), Luís Lopes (20), Luís Mendes (80), Miguel Ferreira (80), Nuno Carolino (10), Orlando Cunha (10)

1 *PhD Student(s):*
Ricardo Luz (100)

2 *Master Student(s):*
Duarte Carreira (100), Miguel Matos Ferreira (50)

1 *Undergraduated Student(s)*:
José Alves

4 *Trainee(s):*
Bernardo Dias, Miguel Martins, Nelson Eiró, Rodolfo Matias

2 *External collaborator(s):*
Alexandra Fernandes, Pedro Teixeira

Total FTE:
13.5

Article(s) in international journals:
4 Direct contribution
4 Indirect contribution
International conference(s):
5 Oral presentation(s)
1 Poster(s)
1 Proceeding(s)
International meeting(s):
7 Oral presentation(s)
National conference(s):
8 Oral presentation(s)
3 Poster(s)
Collaboration meeting(s):
7 Oral presentation(s)
Seminar(s):
3 Seminar(s)
5 Outreach seminar(s)
Completed theses:
1 Master
Book(s) and chapter(s):
1

Executive summary

The Pierre Auger Observatory, the largest Cosmic Ray detector in the world, 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 standard detectors of the Observatory have basically reached their limit and 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 mechanism, by which the energy of cosmic rays is degraded by their interaction with CMB photons in their voyage to Earth. Concerning composition, extensive air shower (EAS) parameters seem to favour heavy composition, whereas the existence of anisotropies favours a light primary. However, the interactions of ultra high energy cosmic rays with the Earth's atmosphere are still poorly understood, and current measurements of the produced air showers aren't able to shed light in a myriad of aspects of these interactions.

The Auger full detector upgrade, consisting on the installation of scintillators on top of the existing water Cherenkov detectors (WCD) 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 analyses and in the development of hadronic models to attain a good description of the EAS 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 only 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.

In the last years the LIP team has been deeply involved 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 gas flux RPCs developed at Coimbra were built in cooperation with São Carlos, SP, Brazil and their installation is foreseen for 2019. 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 has acquired a deep knowledge in shower physics and has developed innovative detailed analyses methods and tools that will allow us to give important contributions in the analysis of the new Auger data. Namely, in 2018, the team has unveiled the relation between the muon content and the interactions that take place at early stages of the shower development.

Sources of funding

Code	Amount	Dates	Description
IF/00820/2014/CP1248/CT0001	50.000 €	2015-01-01 / 2019-12-31	Expl. 2015 LC - IF/00820/2014/CP1248/CT0001
FAPESP/19946/2014	200.000 €	2015-09-01 / 2018-08-31	A new generation of RPC muon detectors for high-precision high-energy cosmic-shower
CERN/FIS-PAR/0023/2017	150.000 €	2017-05-02 / 2019-05-01	Participação portuguesa no Observatório Pierre Auger

Total: 400.000 €

Auger

Lines of work and team organization

The LIP 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.

On the detector development side, the group has strong competences in RPC development and Geant4 simulation. 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 of Auger.

The group pursues an ambitious program organized in the following tasks:

- Detector performance and calibration; Coordinators: Pedro Assis, Raul Sarmento
- MARTA RPCs R&D; Coordinators: L. Lopes, P. Fonte
- MARTA Engineering Array; Coordinators: P. Assis, M. Pimenta
- Shower physics and data analysis; Coordinators: Lorenzo Cazon, Sofia Andringa
- Hadronic models and interface with accelerator measurements; Coordinators: Ruben Conceição, Felix Riehn
- Auger Prime upgrade; Coordinators: Pedro Assis, Bernardo Tomé
- Education and Public Outreach; Coordinator: Pedro Abreu

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

Stated objectives for past year

During 2018 we expected to star the deployment of MARTA and have the first data from the detectors. This would be the final result of a series of steps, namely the production of RPCs, the production of concrete support structures, the development and production of electronics, the deployment of the detectors and their integration with the Central Data Acquisition System of Auger.

Such achievement would allow to start inter-calibration studies between MARTA and other existing detectors, in particular AMIGA (buried muon detectors) and the SSD (scintillators on top of the WCD).

It was also expected to pursue the studies in the Gianni Navarra test-WCD setup to characterize theWCD response to isolated, inclined muons. Namely, the study of calibration parameters and possible degradation of the WCD conditions.

Significant developments were expected on the measurement of the fluctuations of the number of muons. The developed models and simulation framework were to be explored and give significant results on the main parameters driving the cascade development.

Achievements and responsibilities during the past year

During 2018 it was not possible to deploy the stations, mainly due to delays in the production chain. Nevertheless, a great leap forward was taken with the MARTA Engineering Array project. The needed components and parts were produced. The concrete structures were produced in Malargüe and are awaiting deployment. The collaboration has already agreed on the deployment which is being coordinated with the AMIGA group to make it as efficient as possible. On the other hand, 20 RPC modules were finalized in São Carlos and are waiting for shipment to Argentina. Parts for the other 20 modules are being produced. The electronics for the project was produced at LIP in Lisboa and Coimbra.

The cooperation with the AMIGA group was reinforced, exchanging technologies, logistics and infrastructures. Short stays were organized in which possibilities for further cooperation in analyses were explored.

The studies of the WCD response were refined and reached the maturity level for publication by the Pierre Auger Collaboration. An editorial board was formed to finalize/validate the analysis and write the paper.

The study on the shower profile shape was refined, namely on the systematic uncertainties, and it was submitted for publication by the Collaboration.

The studies on the fluctuations of the muon number in extensive air showers have met great progress, and the results were presented in an Auger Collaboration meeting. A publication is in preparation.

The investment in the study of the correlation of the early interactions with the shower observables has unveiled the possibility to probe the energy spectrum of hadrons in proton-air interactions at ultra-high energies through the fluctuations of the muon content of extensive air showers. This work was published by a few authors in the group and received very positive feedback from the collaboration.

The group has increased its responsibility in the upgrade of Auger by developing a muon hodoscope for the test of scintillators at Malargüe. The hodoscope is based on MARTA technology. The group maintains the responsibility of operating the muon hodoscope at the Gianni Navarra setup.

During 2018, L.Cazon and P. Assis continued as leaders of the Shower Physics and Calibration Task of the Pierre Auger Collaboration, respectively, and S. Andringa as member of the Auger Conference Committee.

The group continued its outreach and education activities, namely with programs for summer internships for both high school and university students. The Auger public data was explored with simple analysis for the young public. A 3D visualizer of Auger events, developed at LIP-Minho during an internship, is running permanently at the LIP control room at Técnico. The program is available at LIP and in its public webpages and was presented to the collaboration as a general outreach tool.

The activities of the group on the development of RPC-based muon hodoscopes led to a new line of activity on their possible application in muon tomography, in collaboration with a group at the University of Évora. In 2018, a first demonstrator has been installed in the Lousal mine in Southern Portugal, today a science centre. This effort in being pursued in collaboration with the LATTES group, and its large outreach potential will be exploited.

Lines of work and objectives for next year

In 2019 we will install the MARTA Engineering Array and expect to have the first data before the November collaboration meeting. The first station will be deployed as soon as possible, in the first quarter of the year. The rest of the array deployment will be, as much as possible, tied to the AMIGA detector deployment, to lower costs and strengthen the connection to the Buenos Aires groups. Stays in Argentina are being planned to support the deployment. Data synchronization and management is being discussed with the AMIGA people, who face similar questions. The upgraded electronics of the WCD has suffered significant delay that can impact the scheduling of the MARTA project. Discussions on the data format to be available for the whole collaboration are ongoing.
The SD detailed characterization will continue. We will focus on the calibration of the WCDs, and its inter-calibration with MARTA and AMIGA. We will also study the response of the WCD to very inclined muons and specific trajectories, e.g. trajectories maximizing direct light.

Strong cooperation with the LATTES and RPC R&D group will continue in detector development. Data from the MARTA array will be of key importance for the development of the field, as well as the developments made in the electronics and data acquisition of RPC detectors.

The correlation between fundamental properties of the initial interactions with the different observables at ground will be exploited. Following the published work, the group will study the precision with which measurement on fundamental properties at the highest energies can be made.

The phenomenology related with the muon energy distribution will be pursued to understand its importance and the possibility to infer it using the new detectors to be installed at the Pierre Auger Observatory. Strategies taking advantage of multi-detector measurements will be pursued.

The study on the measurement of the RMS of the number of muons will be finalized and be the subject of a publication.

The line of activity on muon tomography will be pursued and it is likely to become an automomous group in the next year.

The outreach effort will be continued. Namely, we will put effort in lectures and activities directed to 3rd-year master students as a mean to boost the recruitment of master students. Grants will be issued to attract 3rd/4th-year students to develop work that will be used in their thesis. We will also develop experimental setups for demonstrations and classes. The support of high-school students to work with the Auger public data will be pursued, and a discussion was launched on the preparation of a short measurement to be done by high-school students, in the scope of a 1-day Masterclass (similar to the IPPOG's International Masterclasses in Particle Physics). We will also push for the integration of the event visualization program in the Auger outreach pages, particularly in the site of the public data.

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. In Auger, LIP plays a key role in the analysis of the hadronic component of air shower, mainly through muons, which the group will pursue in the following years. On one hand, the group is leading the MARTA project 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 small area of Auger dedicated to lower energy cosmic rays, thus providing high statistics despite its modest size. It will be operated in coincidence with the standard Auger detectors, the upgrade's scintillator and the AMIGA buried detector. Cross-calibration and study of the performance of all detectors are of paramount importance for the Observatory. The LIP group will play a key role in these tasks.

The group will continue the studies in the hadronic sector of 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 cosmic rays.

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

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

MARTA detectors have proved already their capabilities for running in harsh environments showing RPCs are suitable to be used in cosmic ray experiments.

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 fieldwork in Latin America must be wisely chosen.

Opportunities

The group will be in a privileged position for performing detailed and precise measurements of the muon component of air showers 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, as well as the participation in thematic schools and in the LIP Summer Internship programme, is increasing the awareness of this field. The LIP Remote Control Room at Técnico has also significantly 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 funding level of the group might threaten the implementation of all of its research plan. Namely, the installation of the MARTA engineering array will require a considerable financial effort.

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

Auger

Publications

4 Articles in international journals

(with direct contribution from the team)

- *"Probing the energy spectrum of hadrons in proton air interactions at ultrahigh energies through the fluctuations of the muon content of extensive air showers."*, Lorenzo Cazon, Ruben Conceição, Felix Riehn, Phys.Lett. B784 (2018) 68-76
- *"MARTA: A high-energy cosmic-ray detector concept with high-accuracy muon measurement"*, P. Abreu, S. Andringa, P. Assis, A. Blanco, V. Barbosa Martins, P. Brogueira, N. Carolino, L. Cazon, M. Cerda, G. Cernicchiaro, R. Colalillo, R. Conceição, O. Cunha, R. M. de Almeida, V. de Souza, F. Diogo, C. Dobrigkeit, J. Espadanal, C. Espirito-Santo, M. Ferreira, P. Ferreira, P. Fonte, U. Giaccari, P. Gonçalves, F. Guarino, O. C. Lippmann, L. Lopes, R. Luz, D. Maurizio, F. Marujo, P. Mazur, L. Mendes, A. Pereira, M. Pimenta, R. R. Prado, J. Rídký, R. Sarmento, C. Scarso, R. Shellard, J. Souza, B. Tomé, , Eur. Phys. J. C (2018) 78: 333
- *"The MARTA (Muon Array with RPCs for Tagging Air showers) Front-End acquisition system "*, P. Assis, A. Blanco, P. Brogueira, M. Ferreira and R. Luz, IEEE Transactions on Nuclear Science (Volume: 65 , Issue: 12 , Dec. 2018)2920 - 2928
- *"Towards a Next Generation of CORSIKA: A Framework for the Simulation of Particle Cascades in Astroparticle Physics"*, Ralph Engel, Dieter Heck, Tim Huege, Tanguy Pierog, Maximilian Reininghaus, Felix Riehn, Ralf Ulrich, Michael Unger, Darko Veberič, Comput Softw Big Sci (2019) 3: 2

1 International Conference Proceedings

- *"Hadronic Interactions at Ultra High Energies – tests with the Pierre Auger Observatory"*, Sofia Andringa, for the Pierre Auger Collaboration, Proceedings of the 17th conference on Elastic and Diffractive Scattering, EDS, Blois2017, Prague, Czech Republic, June 2017.

1 Books

- *"Introduction to Particle and Astroparticle Physics - 2nd Edition"*, Alessandro de Angelis, Mário Pimenta, ISBN 978-3-319-78180-8

Presentations

5 Oral presentations in international conferences

- Felix Riehn: *"The hadronic interaction model Sibyll 2.3c"*, 2018-05-24, 20th International Symposium on Very High Energy Cosmic Ray Interactions, Nagoya University, Nagoya, Japan
- Ruben Conceição: *"Pierre Auger Observatory: latest results and prospects"*, 2018-06-06, 30th Rencontres de Blois, Particle Physics and Cosmology, Blois, France
- Felix Riehn: *"Probing hadronic interactions at ultra high energies with EAS"*, 2018-08-29, TeV Particle Astrophysics - TeVPA 2018, Berlin, Germany
- Felix Riehn: *"Probing the hadronic energy spectrum in proton air interactions through the fluctuations of the EAS muon content"*, 2018-10-11, UHECR 2018, Ecole Supérieure de Chimie, Paris, France
- Lorenzo Cazon: *"Measurements and tests of hadronic interactions at ultra-high energies with the Pierre Auger Observatory"*, 2018-10-11, UHECR 2018, Ecole Supérieure de Chimie, Paris, France

1 Poster presentations in international conferences

- Sofia Andringa: *"Average shape of longitudinal shower profiles measured at the Pierre Auger Observatory"*, 2018-10-11, UHECR 2018, Ecole Supérieure de Chimie, Paris, France

7 Oral presentations in international meetings

- Lorenzo Cazon: *"Hadronic interactions at the Pierre Auger Observatory"*, 2018-05-04, First joint Workshop IGFAE / LIP, Braga, Portugal
- Pedro Assis: *"MARTA engineering array"*, 2018-05-04, First joint Workshop IGFAE / LIP, Braga, Portugal
- Raul Sarmento: *"Water-Cherenkov detector response to atmospheric muons using a RPC hodoscope"*, 2018-05-04, First joint Workshop IGFAE / LIP, Braga, Portugal
- Luís Mendes: *"RPC Tower for the Upgrade of the Pierre Auger Observatory"*, 2018-07-31, Workshop comemorativo dos 10 anos da Rede Nacional de Física de Altas Energias - RENAFAE 2018, Instituto de Física da Universidade de São Paulo, S. Paulo, Brazil
- Felix Riehn: *"UHE hadronic interaction models"*, 2018-10-18, CFNS workshop on Forward Physics And Instrumentation From Colliders To Cosmic Rays, Stony Brook University, New York, USA
- Felix Riehn: *"Hadronic interaction model SIBYLL"*, 2018-10-30, ISAPP School 2018 - LHC meets Cosmic Rays, CERN, Geneva, Switzerland
- Lorenzo Cazon: *"Air Shower Physics"*, 2018-11-02, ISAPP School 2018 - LHC meets Cosmic Rays, CERN, Geneva, Switzerland

8 Presentations in national conferences

- Pedro Teixeira: *"Geomagnetismo - Os Campos Magnéticos do Sistema Solar"*, 2018-01-10, WCTAE 2018| Workshop em Ciências da Terra, Atmosfera e Espaço, Évora, Portugal
- Ricardo Luz: *"Measuring muons under 12 tons of water "*, 2018-02-17, Jornadas do LIP 2018, Évora
- Lorenzo Cazon: *"Astroparticle Physics at LIP"*, 2018-03-16, Symposium on Data science in (astro)particle physics and the bridge to industry, LIP, Lisboa
- Ricardo Luz: *"MARTA readout system"*, 2018-06-29, 4th IDPASC Student Workshop, U. Coimbra
- Sofia Andringa: *"Particle Observatories - Participação Portuguesa em projectos de astroparticulas: SNO+, Pierre Auger, LZ, AMS"*, 2018-07-03, CIÊNCIA 2018, Lisboa
- Nelson Eiró: *"Multimessenger search"*, 2018-09-05, Summer Student Program 2018 - Final Workshop, LIP, Lisboa
- Rodolfo Matias: *"Develop an RPC - a gaseous particle detector"*,2018-09-06, Summer Student Program 2018 - Final Workshop, LIP, Lisboa
- Raul Sarmento: *"Results from the Pierre Auger Observatory"*, 2018-09-10, XXVIII Encontro Nacional de Astronomia e Astrofísica, Observatório Geofísico e Astronómico da Universidade de Coimbra

3 Poster presentations in national conferences

- Paulo Ferreira: ***"RPC hodoscope to study inclined muons in Auger"***, 2018-02-17, Jornadas do LIP 2018, Évora
- Ricardo Luz: ***"The MARTA (Muon Array with RPCs for Tagging Air showers) Front-End acquisition system -"***, 2018-03-21, PhD Open Days 2018, Instituto Superior Técnico
- Bernardo Dias: ***"Development of a framework for Multi-Messenger Observations with the Auger Observatory"***, 2018-09-10, XXVIII Encontro Nacional de Astronomia e Astrofísica, Observatório Geofísico e Astronómico da Universidade de Coimbra

3 Seminars

- Luís Mendes: ***"Instrumentação em física de partículas"***, 2018-01-22, 3a Escola Avançada de Física Experimental do CBPF, CBPF, Rio de Janeiro, Brazil
- Miguel Ferreira: ***"Effective Methods for Advanced PCB Routing"***, 2018-03-22, LIP Seminar, LIP, Lisboa, Portugal
- Mário Pimenta: ***"The Extreme Universe: high energy cosmic rays"***, 2018-05-24, 8th IDPASC school, Paterna, Valencia, Spain

5 Outreach seminars

- Ricardo Luz: ***"Das profundezas da Terra ao Espaço"***, 2018-05-09, 32th LIP anniversary - Outreach Session, LIP,Lisboa
- Pedro Teixeira: ***"Geomagnetismo - Os Campos Magnéticos do Sistema Solar"***, 2018-11-07, O Espaço vai à Escola (Escola Secundária Pedro Nunes), Lisboa
- Mário Pimenta: ***"Das Partículas ao Universo"***, 2018-11-08, Seminar, Escola Secundária Filipa de Lencastre, Lisboa
- Mário Pimenta: ***"Das Partículas ao Universo"***, 2018-11-09, Seminar, Escola secundária do Restelo, Lisboa
- Pedro Teixeira: ***"Geomagnetismo - Os Campos Magnéticos do Sistema Solar"***, 2018-11-09, O Espaço vai à Escola (Escola Vasco da Gama), Lisboa

Theses

3 Poster presentations in national conferences

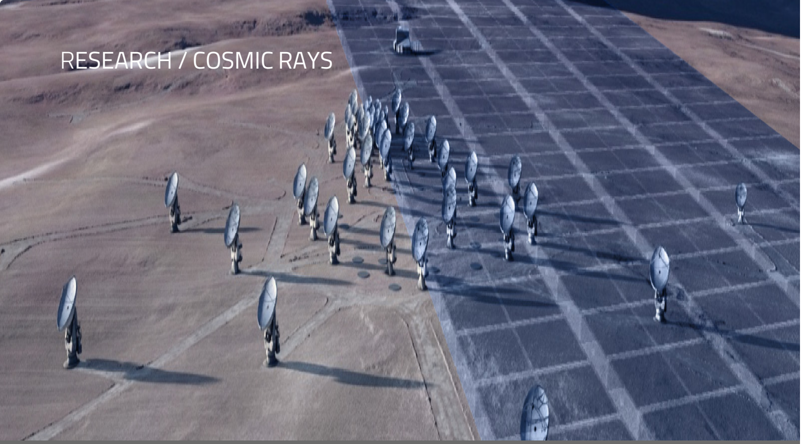
- Paulo Ferreira: ***"RPC hodoscope to study inclined muons in Auger"***, 2018-02-17, Jornadas do LIP 2018Évora
- Ricardo Luz: ***"The MARTA (Muon Array with RPCs for Tagging Air showers) Front-End acquisition system -"***, 2018-03-21, PhD Open Days 2018Instituto Superior Técnico
- Bernardo Dias: ***"Development of a framework for Multi-Messenger Observations with the Auger Observatory"***, 2018-09-10, XXVIII Encontro Nacional de Astronomia e AstrofísicaObservatório Geofísico e Astronómico da Universidade de Coimbra

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: ***"Um projecto de tomografia com muões na mina do Lousal",*** 2017-09-25, (ongoing)

2 Master

- Miguel Matos Ferreira: ***"Average lateral distribution function of muons in 10^{17} eV extensive air showers"***, 2016-09-01 / 2018-10-15, (finished)
- Duarte Carreira: ***"Monitoring system and detector performance of the MARTA engineering array"***, 2018-01-01 , (ongoing)



LATTES

Principal Investigator:
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10 *Researcher(s):*
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4 *External collaborator(s):*
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Total FTE:
3.0

(*) starting in 2019

Article(s) in international journals:
1 Direct contribution
3 Indirect contribution
International conference(s):
2 Oral presentation(s)
International meeting(s):
4 Oral presentation(s)
National conference(s):
2 Oral presentation(s)
Collaboration meeting(s):
21 Oral presentation(s)
Seminar(s):
2 Seminar(s)
2 Outreach seminar(s)
Book(s) and chapter(s):
1
Event(s):
2

Executive summary

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

The goal of LATTES is to design, prototype and construct a ground array able to monitor the Southern gamma-ray sky above 50 GeV, bringing to ground the wide field-of-view and large duty cycle observations characteristic of satellites, with comparable sensitivity and a cost one order of magnitude lower. Such an instrument 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 thus be fully complementary to the large next-generation imaging atmospheric Cherenkov telescope array, CTA. It will 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.

A proof-of-concept design based on a compact air shower array of hybrid detector units composed by small water Cherenkov detectors (WCD) and resistive plate chambers (RPC) was developed in 2016-17 and published at the beginning of 2018. The proposal submitted to the FCT/PTDC call to sustain the project activities for the next three years was approved in May 2018. It includes four major tasks: Detector R&D; Simulation and analysis; Phenomenology; Outreach.

During the last year, the several groups in the world that are developing similar projects started exchanging ideas and expertise, and a first general meeting on a future wide FoV gamma-ray detector for the southern hemisphere was held in Heidelberg last October. The next joint meeting will be held in Lisbon in May 2019, with the aim is to converge into a single collaboration able to find the human and financial resources necessary to build such an ambitious project.

At LIP, we are currently working in a new layout concept, with a central core of WCDs equipped with RPC muon hodoscopes surrounded by a large number of WCDs. This layout will allow to cover a considerably larger area, thus increasing the physics sensitivity and, we believe, providing a good basis for agreement with other groups.

Sources of funding

Code	Amount	Dates	Description
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

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 (and detailed description in the simulation) at temperatures at which water and ice could be simultaneously present.

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 particular focus in deep neural networks.

Task 3 - Phenomenology The main challenges to be addressed are: transient phenomena (detectability of GRBs and 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

Detector R&D

1.1 Adapt the RPC design to operate at a gas flux of 1 cc/min. Build a small hypobaric chamber to test the RPCs at lower pressure.

1.2 Develop a detailed thermal simulation of the detector for several insulations (passive and active), in collaboration with IST experts.

1.3 Study the evolution of the freezing point and the optical properties of sterilized water samples as a function of different solvent concentrations.

Simulation and analysis

2.1 Design optimization, considering in particular, the implementation of a core array equipped with RPC hodoscopes and a sparse array to extend the reach to the highest energies (10-100 TeV).

2.2 Development of improved analyses methods for shower reconstruction and background rejection.

2.3 Evaluate the main background sources for the operation of LATTES.

Phenomenology

3.1 The LIP team will increase its involvement in science case activities.

Outreach

4.1 Development and maintenance of a web site for outreach and educational purposes.

4.2 Iniciatve detector development for outreach.

Achievements and responsibilities during the past year

Detector R&D

1.1 A small hypobaric chamber was designed at LIP-Coimbra. A prototype of a sealed chamber was developed in the framework of RPC R&D LIP group.

1.2 A collaboration with the IST Mechanical Engineering department was established to develop a detailed thermal simulation. A student started a Master thesis on this subject.

1.3 A setup to study the freezing of the water in the WCDs was designed and built. The first test with pure water was made, validating the setup.

Simulation and analysis

A baseline design, able to reach with good sensitivity energies around 100 GeV, has been established both for the detector unit and for the full array.

2.1 Created a fast simulation that allows to significantly increase the number of simulations and explore the high-energy region. First studies on the possibility of the inclusion of a sparse array were made.

2.2 Developed improved analyses methods for shower reconstruction and background rejection, combining the measurements from different detector components. Preliminary studies on the use of artificial neural networks to explore the signal patterns of showers at ground were conducted.

2.3 Assessed the background rate due to atmospheric particles (and showers) and developed strategies to handle it.

Phenomenology

3.1 The LIP team increased its involvement in 2018, particularly since a researcher with expertise in gamma-ray astrophysics joined the group. Preliminary studies on the detectability of extended sources (Fermi Bubbles) and transients (GRB and flares) were conducted, with encouraging results.

Outreach

4.1 A webpage created with information about the project: talks, seminars, groups involved.

4.2 An RPC hodoscope demonstrator is in an advanced construction phase and will be installed at the beginning of 2019 in the Lousal Mine, in southern Portugal, today a Science Centre.

Lines of work and objectives for next year

Presently there are several groups in the world developing similar projects. An effort to converge in a single collaboration, able to find the human and financial resources necessary to build such ambitious project is underway, and a joint meeting of all the groups will be held in Lisbon in May 2019. The work and objectives of the LIP team for next year are organized in the following tasks.

Task 1 - Detector R&D

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

1.2 Finalise the detailed thermal simulation of the detector in the environment where the experiment should be installed (altitudes of around 5000 meters in the Andes). This work is being carried out 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. Experts from Chemical and Biochemical Technology Institute (ITQB) will collaborate in the project. The irradiation facilities at CTN may be used.

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 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 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.

Medium-term (3-5 years) prospects

The LATTES project is being developed with the support of a 3-year grant from FCT. This is adequate to establish the feasibility of the Portuguese participation in the design, construction and operation of a future wide field-of-view high-altitude gamma-ray observatory in South America. The project is conceptually and technologically innovative, and the LIP group may have a significant contribution, due to its background in cosmic ray physics, detector simulation techniques and on the construction and operation of standalone outdoor RPCs. The next phase has to be carried in the framework of a large international collaboration. Our group is actively engaged in the establishment of such a collaboration.

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-recognized 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 the 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 of 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.

Publications

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

- *"Design and expected performance of a novel hybrid detector for very-high-energy gamma astrophysics"*, P. Assis, U. Barres de Almeida, A. Blanco, R. Conceição, B. D'Ettore Piazzoli, A. De Angelis, M. Doro, P. Fonte, L. Lopes, G. Matthiae, M. Pimenta, R. Shellard, B. Tomé, Astropart.Phys. 101 (2018) 36-36

1 Books

- *"Introduction to Particle and Astroparticle Physics - 2nd Edition"*, Alessandro de Angelis, Mário Pimenta, ISBN 978-3-319-78180-8

Presentations

2 Oral presentations in international conferences

- Bernardo Tomé: *"LATTES: a new detector concept for a gamma-ray experiment in the Southern hemisphere"*, 2018-06-06, 30th Rencontres de Blois, Particle Physics and Cosmology, Blois, France
- Mário Pimenta: *"A new EAS experiment in the Southern hemisphere"*, 2018-07-06, Fifteenth Marcel Grossmann Meeting, University of Rome, Rome, Italy

4 Oral presentations in international meetings

- Ruben Conceição: *"LATTES: a next generation detector concept for (very)-high-energy gamma-rays"*, 2018-05-04, First joint Workshop IGFAE / LIP, Braga, Portugal
- Mário Pimenta: *"Wide field of view gamma-ray observatory in Southern hemisphere"*, 2018-05-18, AGILE 16th Science Workshop - Fast and AGILE: Multimessenger Astrophysics and Beyond, Rome, Italy
- Mário Pimenta: *"LATTES"*, 2018-10-08, SGSO F2F Meeting, Heidelberg, Germany
- Ruben Conceição: *"LATTES simulated performance"*, 2018-10-09, SGSO F2F meeting, Heidelberg, Germany

2 Presentations in national conferences

- André Torcato: *"Looking for astrophysical gammas with a next generation detector"*, 2018-09-05, Summer Student Program 2018 - Final Workshop, LIP, Lisboa
- Giovanni La Mura: *"LATTES: a novel detector concept for a gamma-ray experiment in the Southern hemisphere"*, 2018-09-10, XXVIII Encontro Nacional de Astronomia e Astrofísica, Observatório Geofísico e Astronómico da Universidade de Coimbra

2 Seminars

- Mário Pimenta: *"The Extreme Universe: high energy cosmic rays"*, 2018-05-24, 8th IDPASC school, Paterna, Valencia, Spain
- Ruben Conceição: *"A next generation wide field of view detector to study very high-energy gamma rays in the Southern hemisphere"*, 2018-12-12, FCUL Seminars, Faculty of Sciences of the University of Lisbon, Portugal

2 Outreach seminars

- Mário Pimenta: *"Das Partículas ao Universo"*, 2018-11-08, Seminar, Escola Secundária Filipa de Lencastre, Lisboa
- Mário Pimenta: *"Das Partículas ao Universo"*, 2018-11-09, Seminar, Escola secundária do Restelo, Lisboa

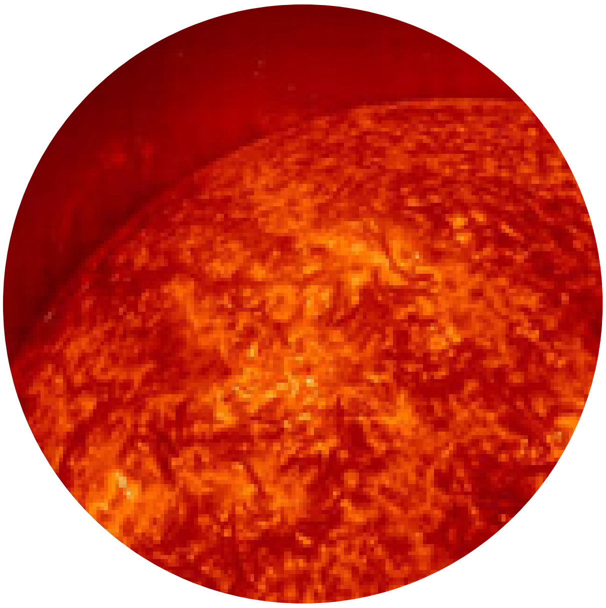
Organized Events

1 Workshops

- *"LATTES: Multivariate Analyses Workshop"*, [WS] 2018-09-14 / 2018-09-14, University of Granada, Granada, Spain

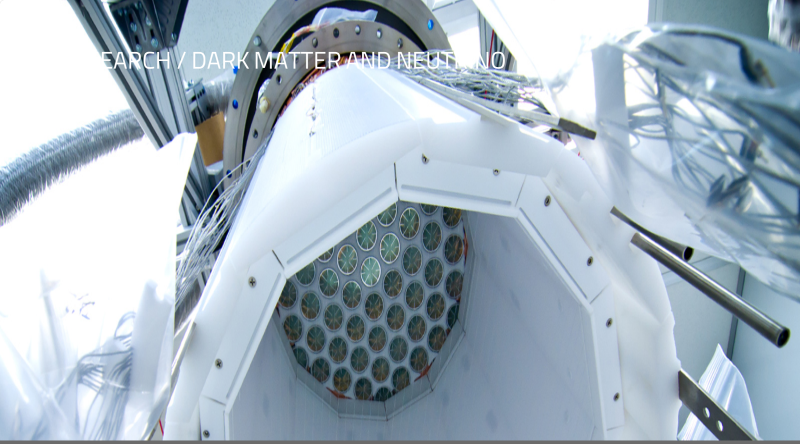
1 Collaboration Meetings

- *"7th LATTES Meeting"*, 2018-09-28 / 2018-09-28, Coimbra University, Coimbra, Portugal



[Dark matter and neutrino]

Dark Matter
SNO+ / DUNE
SHiP



DARK MATTER

Participation in dark matter experiments: LUX and LZ

Principal Investigator:
Isabel Lopes (62)

9 *Researcher(s):*
Alexandre Lindote (90), Andrey Morozov (10), Cláudio Silva (83), Francisco Neves (70), Helmut Wolters (7), José Pinto da Cunha (37), Ricardo Cabrita (33), Sumanta Pal (67), Vladimir Solovov (50)

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

2 *PhD Student(s):*
Guilherme Pereira (100), Paulo Brás (95)

3 *Master Student(s):*
Andrey Solovov (100), Cédric Pereira (67), Jacinto Fonseca (33)

Total FTE:
9.6

Article(s) in international journals:
3 Direct contribution
3 Indirect contribution
Internal note(s):
4 Collaboration note(s)
International conference(s):
8 Oral presentation(s)
1 Poster(s)
International meeting(s):
1 Oral presentation(s)
National conference(s):
4 Oral presentation(s)
Collaboration meeting(s):
34 Oral presentation(s)
Seminar(s):
3 Seminar(s)
1 Outreach seminar(s)

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 search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs), aiming at their direct detection with two-phase xenon Time Projection Chambers (TPCs).

LUX (Large Underground Xenon) is a retired experiment based on a 250 kg xenon TPC that has published three previously world leading limits on the spin-independent cross section for WIMP-nucleon scattering in the 5-1000 GeV mass range. The analysis of the science and calibration data accumulated by LUX analysis have continued even after its decommission in 2017, resulting in 14 papers already published (or accepted for publication) and 9 more in preparation. These papers cover a large variety of topics including the search of axions, sub-GeV dark matter particles and Xe isotopes rare decays, as well as innovative calibration techniques, several aspects of the physics of xenon as detector medium and the detector performance.

LUX-ZEPLIN (LZ) is a second-generation dark matter direct detection experiment that will be deployed at the 4850-feet level of the Sanford Underground Research Facility (SURF) in Lead, South Dakota, USA. The LZ detector uses 7 tonnes active mass of purified xenon in a dual phase TPC to search for potential signals from WIMPs. With 5.6 tonnes fiducial mass and a 1000 live-days long dark matter search, the projected spin-independent cross section sensitivity is 1.6×10^{-48} cm^2 for a 40 GeV WIMP mass, ~50 times better than the current best limit. LZ parts have started to arrive at SURF in 2018 and the detector and ancillary systems have started to be assembled. The underground deployment of LZ is scheduled for 2019 and commissioning is expected to start in the beginning of 2020. In parallel with the detector construction and deployment, an intense activity of simulation, R&D of data analysis tools, their implementation and validation is taking place.

In 2018, the dark matter LIP group has made crucial progress regarding 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 (NDBD, or $0\nu2\beta$) of ^{136}Xe, the second most important physics goal of LZ. We have also studied the sensitivity of LZ to the double beta decay of ^{134}Xe. The group has also participated in LUX data analysis. Our members occupy four coordination positions in the collaboration in most activities where the group is involved, from control system to physics analysis.

The proposal submitted to the FCT PTDC call to fund the participation of LIP in LZ for the next three years was approved in May 2018.

Sources of funding

Code	Amount	Dates	Description
PTDC/FIS-NUC/1525/2014	199.280 €	2016-01-01 / 2018-08-31	Direct Detection of Dark Matter: Participation in the LUX-ZEPLIN and LUX Experiments
PTDC/FIS-PAR/28567/2017	239.807 €	2018-09-01 / 2021-08-31	Participation in dark matter experiments LZ

Total: 439.087 €

Dark Matter

Lines of work and team organization

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

- Data analysis tools for LUX and LZ, encompassing algorithms and techniques for pulse identification & characterization, detector related corrections and high-level analysis from the definition of the datasets and the development of quality cuts, up to the high level physics analysis (Francisco Neves, Paulo Brás and Andrey Solovov).
- Physics Beyond dark matter search with the LZ detector: neutrino physics studies, search for neutrinoless beta decay in ^{136}Xe and ^{134}Xe and other Xe rare decays such as double capture in ^{124}Xe and ^{126}Xe, with a strong focus on the use of machine learning algorithms for improving the signal to background discrimination (Alexandre Lindote, Cláudio Silva, Paulo Brás, Sumanta Pal, Francisco Neves)
- Position reconstruction methods (Claudio Silva, Guilherme Pereira, Cedric Pereira, Vladimir Solovov).
- Modelling and GEANT4 based simulation of the background in LZ (Alexandre Lindote)
- Control systems (Vladimir Solovov, Cedric Pereira, Ricardo Cabrita and Guilherme Pereira);
- Modeling, simulation and measurement of the reflectivity of rough and diffuse surfaces (Cláudio Silva and Francisco Neves).

The LIP team is represented by the PI of the project (I. Lopes) in the LUX Executive Board and LZ Institution Board. Francisco Neves is co-PI of the project.

Stated objectives for past year

1. LZap data analysis toolkit: Improvement of several algorithms, namely the pulse classifier, HG-LG mixing and pulse grouping algorithms, as well as the position reconstruction tool.
2. To explore several ways to improve the sensitivity of LZ to ^{136}Xe 0v2β decay.
3. Rare decay events in Xe isotopes: i) Finish the analysis of LUX Run04 data for the double electronic capture (2EC) in ^{124}Xe and combine it with the Run03 analysis to set a global lower limit for the half-life of this rare decay from the LUX experiment. ii) Perform sensitivity studies of LZ to 2v2ß and 0v2ß decays in ^{134}Xe.
4. Integrate the Data Quality Monitor (DQM) with the other elements of the LZ Data Pipeline (e.g. Run Control and Event Builder); Integrate LZap into the DQM.
5. Continuation of reflectivity measurements and investigation of PTFE fluorescence.
6. Development of machine-learning software for the LZ control system.
7. Continue with the responsability of keeping the background repository, finish the migration of the repository from the Excel format to the full database, add additional functionality to the database implementation.
8. Organize in Coimbra an LZ Collaboration meeting and a LUX Data Analysis Workshop.

Achievements and responsibilities during the past year

LUX-ZEPLIN

1. LZ Analysis Framework (LZap)

- Implementation and testing of a pulse classification algorithm on the official LZ analysis framework. A complete event reconstruction on the LZ detector depends on this critical algorithm, which lays the foundation for the physics analysis of the experiment. The algorithm was tested on a full collaboration effort, the second Mock Data Challenge (MCD-2), and was proven successful. (Paulo Brás under the supervision of Francisco Neves and Alexandre Lindote).
- Study of machine-learning methods for pulse classification, with some viable methods tested successfully: artificial neural networks and random decision forests provide high classification efficiency. The methods were tested using LUX and LZ simulated data, having efficiencies over 99.5%. Convolutional neural networks were also tested with synthetic data, with high classification efficiency. (Paulo Brás under the supervision of Francisco Neves and Alexandre Lindote).
- Upgrade of two other LZap modules that have been developed by the team in 2017: the module synchronizing the pulses acquired in high and low gain (HG-LG mixing); and the module that groups pulses corresponding to specific interactions in the sensitive volume. They had been successfully used/benchmarked within the Mock Data Challenge 2 (MDC2). (Francisco Neves).
- Position reconstruction module for LZAP data processing infrastructure was updated to support new features required for MDC2 processing. An alternative version of the module has been developed for the studies of the effect of PMT failure on detector performance that were carried at the University of Oxford (Guilherme Pereira and Vladimir Solovov).

2. Neutrinoless double beta decay in ^{136}Xe in LZ

- Complete model with description of the backgrounds for neutrinoless double beta decay searches, using the most recent simulations of radioactivity in the LZ detector components and laboratory.

Calculation of the sensitivity of LZ to NDBD. It is already apparent that LZ can be a competitive detector in this field, having sensitivity comparable to that of the current best dedicated experiments.
A paper is almost ready to be submitted for publication. Paulo Brás is co-corresponding author of the paper.
This work has been done mostly by P.Brás under the supervision of Alexandre Lindote and Francisco Neves and with the participation of Cláudio Silva.
Development of improved pulse finding algorithms to be used, in particular, in the context of the 0v2ß decay searches. The performance tests of the algorithm using MDC2 data indicate it may be suitable for usage over all energies of interest in LZ data. (F. Neves).

3. Other Xe rare event searches with LZ:

- During this year the background model to study the double beta decay of ^{134}Xe (both the normal 2-neutrino mode and the neutrinoless mode) was finalised, by including the contributions of the radioactivity in materials used to build the detector, contaminants mixed in the xenon (radon, Kr and Ar), solar neutrino interactions and 2-neutrino double beta decay of ^{136}Xe. Preliminary estimates of the sensitivity for both decay modes were done using the TRolke method, which showed the potential for LZ to greatly improve the current best limits for the half-lives of these decays. A study using the more robust Profile Likelihood Ratio method has been started, to take advantage of our knowledge of the contributions of the individual backgrounds and their uncertainties. (Sumanta Pal in collaboration with Alexandre Lindote and Cláudio Silva).

4. Backgrounds:

- During 2018 most of the subsystems of the detector entered the assembly stage, with many new parts being added to the detector design and thus the background model. This led to hundreds of materials being assayed for their radioactive contamination and tested in the model for approval before being used. In parallel, work on estimating non-standard backgrounds continued with studies on e.g., gamma-X events, random coincidences of isolated S1 and S2 signals (from various sources) and ion recoils near the walls due to implantation in the PTFE of the long-lived radon daughter ^{210}Pb. Alexandre Lindote (AL) led the effort of the Backgrounds Working Group (BGWG) to obtain the distribution of background events in the WIMP search region, writing the analysis scripts and developing the cuts which will serve as foundation for when data acquisition starts. During this process, AL discovered and corrected several issues with the simulated data, knowledge that will be used to improve the accuracy of the fake data in the next MDC.

5. Detector Quality Monitor (DQM) We took full responsibility for the development and implementation of the real time infrastructure for LZ. During 2018, a complete first version of the software was deployed and benchmarked using MDC2 data. That version already includes integration with the Control System. (Francisco Neves).

6. Material optical measurements

- Both at the LIP lab in Coimbra and in collaboration with the Technical University of Munich (TUM), R&D measurements were carried out towards the possible identification and characterization of the fluorescence of PTFE when irradiated with xenon scintillation light. So far only measurements at room temperature have been done and no clear indications of fluorescence production by the VUV light has been observed.
- We measured the reflectivity of PTFE samples cut from the panels used in LUX. The objective is to investigate any possible degradation of the PTFE reflectivity after being immersed in liquid xenon (LXe) for long periods of time and exposed to large fluxes of VUV, namely during the detector conditioning stages. No degradation was observed within the precision of the method (~0.1%).
- We completed the feasibility study regarding the measurement of the reflectivity of LZ materials (e.g. titanium) using the technique and setup developed for the case of the PTFE, which has a much higher reflectivity (closed to 100%).

7. LZ Control System Concerning our responsibilities on the LZ control systems, our main achievements were the following: 1) The Ignition infrastructure for LZ was updated to provide convenient and robust development environment available for all interested parties in the Collaboration. In particular, the following features were included: i) Versioning system updated to improve reliability and facilitate collaborative development; ii) Facility for importing channel configuration from documentation provided by subsystem owners. iii) MODBUS wrapper – a universal solution for integration of hardware with non-standard interfaces – was developed and tested; iv) Update to Ignition automation module with focus on improved robustness and script readability. 2) Interfaces between Ignition and several important subsystems - such as Siemens PLC, Power supply for electronic racks, PMT high voltage supply, Outer Detector optical calibration - were successfully tested. 3) GUI development for LZ circulation and cryogenic subsystems as well as for Kr removal installation at SLAC is under way in close collaboration with respective system owners.

8. Outreach

- **Cloud chamber:** The cloud chamber was exihibited in several events. (Francisco Neves).
- **Upgrade of the cloud chamber:** the mechanical design of the portable (small, 1x) chamber and the construction of a new control/monitor electronics box were done. In particular, this box includes a new design of the power drive board for the Peltier coolers and alcohol heater. The power drive board was design having in mind the planned construction of a bigger (4x) cloud chamber. (Francisco Neves).
- A month-long Summer Internship program for three university-level students with the project "Construção de um detector de muões portátil", Physics Department of the University of Coimbra, July 2018. (F. Neves, and A. Lindote).
- iA project "Matéria escura: à procura da agulha no palheiro", integrated in the University of Coimbra Summer University 2018 project, with an intensive week-long scientific program for five high-school students, Coimbra, July 2018. This project consists in searching for WIMPs in real LUX data where some fake WIMP signals were added (Alexandre Lindote).

LUX

- DEC in ^{124}Xe**:** The search for possible signals of double electron capture (DEC) in the ^{124}Xe isotope in the second science run of the LUX detector continued in 2018. Applying basic data quality cuts, the fiducial volume for this search was optimised for each of the periods of the run using the sensitivity estimate provided by the TRolke method. Further data quality cuts were then explored to remove a population with an S2/S1 ratio lower than expected visible under the electron recoil band. A cut is currently being developed for these events. (Alexandre Lindote).
- We improved the model of backgrounds in the walls of the detector (wall background) caused by the recois of ^{206}Pb and the decays of ^{210}Pb and ^{210}Bi. (Claudio Silva).

In 2018, the LIP group members had the following coordination positions in the LZ and LUX collaboration structures**:**

In LZ:

- Vladimir Solovov: coordinator of the LZ slow control system (L3 in the LZ management hierarchy).
- Alexandre Lindote was elected coordinator of the backgrounds working group of the LZ collaboration, while still keeping the L3 position in the LZ project as responsible for the background model of the experiment.
- Francisco Neves: Coordinator of the LZ offline Analysis and Reconstruction working group (WBS (1.11.5.2)).
- Claudio Silva: co-coordinator of the LZ High-ER group.

In LUX:

- C. Silva was LUX Data Analysis coordinator (January to April 2018).

Lines of work and objectives for next year

In 2019, the work will be focused mostly in LZ, particularly on the following topics:

1. LZ Analysis Framework (LZap)

- Improvement of the current pulse classification algorithm: study other machine-learning methods, such as clustering algorithms, that may have several advantages over blackbox methods like artificial neural networks, namely the ability to detect pathological features or populations in the data.
- The new requirements for the HG-LG mixing algorithm were already presented/drafted to the WBS1.11 working group and the implementation of the updated algorithm should start soon to be ready to MDC-3. The interaction finder algorithm is also expected to change significantly in the near future for supporting new physics requirements.
- Publication of a paper on machine learning methods in dark matter direct detection experiments with dual-phase xenon technology.
- Based on feedback from MDC2, the position reconstruction module will be updated in order to improve its speed, reduce number of mis-reconstructed events and give move information for analysis. Most importantly, we plan to: i) Update spline fitting library; ii) Implement maximum likelihood fitting to better handle low-energy events; iii) Provide additional parameters useful in the downstream analysis.

2. Neutrinoless double beta decay in ^{136}Xe in LZ

- Completion of the backgrounds analysis of the laboratory rock using the most recent assays and simulations.
- Publication of a scientific paper by the collaboration with the sensitivity studies for neutrinoless double beta decay searches.
- Test and benchmark the effciency of machine learning algorithms for the identiffication of 0v2ß events in LZ.

3. Other Xe rare event searches with LZ: Double beta decay of 134Xe: The sensitivity study using the Profile Likelihood Ratio method will continue, together with an optimisation of the fiducial volume for this decay, followed by the publication of the results. Both approaches are expected to lead to an improvement of the sensitivity estimates obtained with the TRolke method, which already largely surpass the current best limits for both decay modes of this isotope.

4. Backgrounds: As the LZ construction is finalised, the focus of the backgrounds working group is gradually shifting from generating estimates of each background to the study of backgrounds in real data and the development of tools to veto and adjust them to what is observed, in order to allow the publication of a first WIMP search limit just a few months into the LZ run, accompanied by a dedicated publication with a detailed description of the background model. In 2019 the LZ collaboration will carry out its third Mock Data Challenge (MDC-3), with more realistic data. The BGWG will actively contribute to this effort, ensuring the correct simulation of the various background sources, and will use the opportunity to test preliminary versions of the background analysis tools being developed for the model validation. Another big focus this year will be the development of a more versatile and unified tool to allow the generation of background models for different searches (e.g. axions, rare decays) in different energy regimes, as the existing model is mainly focused in the search for the standard WIMP.

5. DQM: Integrate the DQM with the Event Builder and eventually other UG online infrastructures (e.g. real time event display). Develop a more realistic set of analysis macros using data from the MDC3.

6. PTFE optical properties: Continue/finish the R&D work for identification and characterization of the PTFE fluorescence when irradiated with xenon scintillation light at low temperature (~ -100ºC).

7. LZ control System: 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 with Hardware; vi) Participation in deployment of Ignition infrastructure underground.

In LUX, the following tasks will be finished in 2019:

1. Regarding the double electron capture in ^{124}Xe, we expect to finish the optimisation of the cuts and estimate their efficiency using ^{14}C calibration data. This will allow for the removal of the population of outliers and determine the sensitivity and the limit of LUX to this decay in LUX Run4. The same analysis will then be applied to LUX Run3, and the results combined and published. Taking advantage of the LZ background model already developed for the ^{134}Xe analysis, we will then proceed to estimate the sensitivity of LZ to the DEC decay in ^{124}Xe. The neutrinoless mode of this decay, which implies physics beyond the SM, will then be explored in both LUX and LZ, by looking for high-energy gammas carrying the energy of the decay (2.86 MeV) in coincidence with the 63 keV signal.
2. The wall model will be continued both for LUX and LZ. For LZ, it is planned to develop a radial model and update the current estimates of the background leakage from the walls in the fiducial region of the detector.

Medium-term (3-5 years) prospects

In the beginning of 2020, the LZ detector will be commissioned and will initiate data taking. It is planned to have a 1,000 days-live science data acquisition. Therefore, the plan includes research to be carried out within LZ along two main lines:

1. Contributions to the dark matter particle identification.

2. Search for neutrinoless double beta decay and other rare decays.

Regarding point 1, the project includes several scientific and technical contributions to the LZ experiment that are already ongoing, namely the control system, the data quality monitor, the development and implementation of data analysis tools, background modeling and simulation. We also plan to investigate some additional physics topics, such as to study the sensitivity of LZ to *leptophilic WIMPs* and, once the data is available, to search for the possible interactions of this type of WIMPs.

As for point 2, the plan is focused on the optimization of the methods to search for rare Xe decays in LZ, in particular $0\nu2\beta$ decay of ^{136}Xe, which would indicate new physics beyond the standard model. Furthermore, the project includes the investigation and experimental demonstration of a new method to discriminate $0\nu2\beta$ decay in liquid xenon in a dual-phase (liquid/gas) xenon time projection chamber. The $2\nu2\beta$ and $0\nu2\beta$ decays in ^{134}Xe, as well as the $2\nu2$EC and 0νEC will also be investigated with LZ.

SWOT Analysis

Strengths

The group is a well-established and highly considered member of the LUX and LZ Collaborations. Besides the long experience in dark matter 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 physics 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, 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, to operate liquid xenon detectors.

Weaknesses

Currently we have only two PhD students and 2 Master Students. We have taken important steps (outreach, internships, etc) to attract more students, but it takes time.

There is shortage of several pieces of equipment and others are obsolete. The funding is very limited, which does not allow to participate in the experiments and buy equipment as we need.

Opportunities

LZ is the most competitive dark matter experiment in the world, with a high potential for detecting WIMPs. To participate in such experiment is 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 postdocs and attract PhD students. In 2018, we have hired a new researcher and an engineer.

Threats

The project was funded in the framework of the 2017 FCT/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.

Publications

3 Articles in international journals

(with direct contribution from the team)

- ***"Position Reconstruction in LUX"***, A.S. Akerib et al. , JINST 13 (02), P02001, 2018
- ***"Calibration, event reconstruction, data analysis, and limit calculation for the LUX dark matter experiment"***, D.S. Akerib et al., Phys. Rev. D 97, 102008, 2018
- ***"Liquid xenon scintillation measurements and pulse shape discrimination in the LUX dark matter detector"***, D.S. Akerib et al., Phys. Rev. D97 (11), 112002, 2018

2 Internal notes

- ***"2EC analysis in Run03 and Run04"***, Alexandre Lindote, LuxDB000529
- ***"Mock Data Challenge 2 Report"***, Alexandre Lindote, LzDB000140

2 Collaboration notes with internal referee

- ***"Study of SE delayed emission in LUX"***, Claudio Silva, LzDB00000123
- ***"Mock Data Challenge 2 report"***, MDC-2 participants, LzDB00000140

Dark Matter

Presentations

8 Oral presentations in international conferences

- Isabel Lopes: *"The Dark Matter Problem"*, 2018-05-28, Workshop Bridging the Dark Gap: Dark Matter in Particle Physics and Astrophysical Studies, Rio de Janeiro, Brazil
- Francisco Neves: *"The LUX and LZ experiments"*, 2018-06-19, 14th Patras Workshop on Axions, WIMPs and WISPs, Hamburg, Germany
- Paulo Brás: *"The 136Xe neutrinoless double beta decay search with LZ"*, 2018-06-22, BEACH 2018 - XIII International conference on beauty, charm and hyperion hadrons, Peniche, Portugal
- Cláudio Silva: *"Recent Results from LUX"*, 2018-06-25, 14th International Workshop Dark Side Of the Universe, Annecy-le-Vieux, France
- Isabel Lopes: *"Results from Direct Detection Dark Matter Experiments"*, 2018-08-20, Rencontres du Vietnam: Windows on the Universe, Quy Nhon, Vietnam
- Isabel Lopes: *"Latest results of LUX dark matter experiment"*, 2018-08-28, 2018 TeV Particle Astrophysics Conference (2018 TeVPA), Berlin, Germany
- Isabel Lopes: *"Recent advances in the low energy calibration of large liquid noble gases detectors"*, 2018-10-07, 14th International Symposium on Radiation Physics (ISRP-14), Cordoba, Argentina
- Vladimir Solovov: *"Current status of LZ and LUX Dark Matter Experiments"*, 2018-10-24, IV International Conference on Particle Physics and Astrophysics (ICPPA), Moscow, Russia

1 Poster presentations in international conferences

- Paulo Brás: *"The 136Xe neutrinoless double beta decay search with LZ"*, 2018-06-06, Neutrino 2018 - XXVIII International Conference on Neutrino Physics and Astrophysics, Heidelberg, Germany

1 Oral presentations in international meetings

- Alexandre Lindote: *"Backgrounds Update & Summary"*, 2018-01-11, LZ Status and Operations Planning DOE Review 2018, LBNL, berkeley, USA

4 Presentations in national conferences

- Alexandre Lindote: *"Latest results from LUX"*, 2018-02-17, Jornadas do LIP 2018, Évora, Portugal
- Paulo Brás: *"The 136 Xe neutrinoless double beta decay search with LZ"*, 2018-06-28, IDPASC PhD workshop 2018 , Coimbra, Portugal
- Alexandre Lindote: *"O Enigma da Matéria Escura"*, 2018-09-01, FISICA 2018 National Physics Conference,, Covilhã
- Francisco Neves: *"Looking for the dark side of the Universe"*, 2018-09-10, XXVIII Encontro Nacional de Astronomia e Astrofísica, Coimbra, Portugal

3 Seminars

- Isabel Lopes: *"Searching for Dark Matter with LUX and LUX-ZEPLIN"*, 2018-03-20, Universita' degli Studi di Rome "Tor Vergata", Rome, Italy
- Isabel Lopes: *"Direct Search for Dark Matter: the problem and the present status"*, 2018-05-08, University of Bucarest, Bucarest, Romenia
- Francisco Neves: *"Looking for the dark side of the Universe",*", 2018-10-03, Café com Física, Coimbra, Portugal

1 Outreach seminars

- Alexandre Lindote: *"Matéria Escura: das galáxias ao fundo de uma mina"*, 2018-03-16, Lojas de Saber, Exploratório Infante D. Henrique, Coimbra, Portugal

Organized Events

2 Collaboration Meetings

- *"Spring 2018 LZ Collaboration Meeting"*, [Coll-Mtg] 2018-04-17 / 2018-04-20, Coimbra, Portugal
- *"LUX Data Analysis Workshop"*, [Coll-Mtg] 2018-04-22 / 2018-04-24, Coimbra, Portugal

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)

3 Master

- Natalija Novak: *"Study of neutrino interactions in the LZ Dark Matter detector"*, 2016-10-01 , (ongoing)
- Andrey Solovov: *"Development of analysis techniques for the identification of 0v2ß event topologies and their characterisation"*, 2017-09-01 , (ongoing)
- Jacinto Fonseca: *"Detection of Magnetic Inelastic Dark*

SNO+ / DUNE

Collaboration in the SNO+ and DUNE experiments

Principal Investigator:
José Maneira (67)

9 *Researcher(s):*
Amélia Maio (15), Fernando Barão (25), Francisco Neves (*), Gersende Prior (100), Nuno Barros (*), Pedro Jorge (10), Sofia Andringa (50), Valentina Lozza (100), Vladimir Solovov (*)

1 *Technician(s):*
Américo Pereira (17)

2 *PhD Student(s):*
Ana Sofia Inácio (100), Stefan Nae (100)

1 *Master Student(s):*
Glória Pereira (41)

2 *Undergraduate Student(s):*
João Carlos Antunes, Miguel Bernardo

4 *Trainee(s):*
Alexandra Lopes, Daniel Goncalves, Eduardo Castanho, Jessica Gonçalves

1 *External collaborator(s):*
Yan Liu

Total FTE:
6.2

(*) starting in 2019

Article(s) in international journals:
2 Indirect contribution

International conference(s):
3 Oral presentation(s)
2 Poster(s)
5 Proceeding(s)

National conference(s):
1 Oral presentation(s)
3 Proceeding(s)

Collaboration meeting(s):
1 Oral presentation(s)

Seminar(s):
1 Seminar(s)

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 neutrinoless double-beta decay (DBD, or 2ß) 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 water phase data, with leadership or strong contributions to physics analyses (backgrounds and antineutrino studies), calibrations, and data quality. The scintillator fill is expected in 2019, and so the group's efforts will gradually shift 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 will initially focus 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

Code	Amount	Dates	Description
IF/00863/2013/CP1172/CT 0006	50.000 €	2014-01-01 / 2018-12-31	Expl. 2014 GP - IF/00863/2013/CP1172/CT0006
PTDC/FIS-NUC/0640/2014	184.276 €	2016-02-01 / 2018-10-31	Participação portuguesa na experiência de física de neutrinos SNO+
IF/00248/2015/CP1311/CT 0001	50.000 €	2017-01-01 / 2021-12-31	Expl. 2015_VL - IF/00248/2015/CP1311/CT0001

Total: 284.276 €

SNO+

Lines of work and team organization

The group's SNO+ activities are organized according to three main lines of work, each one in turn divided into specific tasks.

- Detector calibration (JM)
  - Internal source deployment: production of Umbilical Retrieval Mechanism (URM) at Coimbra; software tools for calibration source information.
  - Analysis of laserball calibration data: analysis of the water phase data and preparation of scintillator phase analysis.
  - Low energy gamma sources: all aspects, from fabrication to deployment, related to the use of low energy gamma sources in the scintillator phase.
- Detector and data-taking performance (GP, VL)
  - Data quality and Run Selection: coordination and participation on the review of the quality of the data for all Physics runs; development of automatization tools.
  - Backgrounds: coordination and analysis of the stability and spatial distribution of the backgrounds in the water phase, testing the effects of water recirculation, calibrations, and other detector conditions; ongoing coordination of studies for the scintillator (+Te) phase.
- Analysis of physics data (SA, FB)
  - Anti-neutrinos: preparation of the general analyses tools for the different SNO+ phases, as well as on specific calibrations for anti-neutrino signals, with an AmBe source.
  - Reconstruction: review of the SNO+ Reconstruction performance for the water phase.

List of internal SNO+ leadership responsibilities taken by group members: Anti-neutrino Physics Group (SA), Backgrounds Working Group (VL), Calibration Source Review Committee (JM), Optical Calibration Working Group (JM, GP(until Dec. 2018)), Reconstruction Review Committee (GP), Run Selection Committee (GP, until Dec. 2018). In addition, we are responsible for software documentation, within the software validation group (ASI), and for overseeing the SNO+ database infrastructure (SN). In 2019, we expect a new group member (Nuno Barros, NB), currently co-leader of the Reconstruction group and the Water Phase analysis.

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
Main objectives that we had planned for 2018, listed by activity area:

- Calibrations:
  - Finalize the preparation of the source insertion system for the scintillator phase;
  - Analyze the internal and external laserball scans to obtain the optical calibration parameters;
  - Participate in the deployment and analysis of the AmBe neutron source;
  - Finalize the development of two new gamma sources for the pure scintillator phase.
- Data quality and Run Selection:
  - Complete the data quality tables with data-packing issues;
  - Deploy the fully automated run selection framework;
- Data analysis:
  - Continue a background stability and uniformity analysis, checking for changes due to activities in the detector;
  - Participate in the water phase physics publications;
  - Start an analysis of cosmic muons in SNO+;
  - Continue the internal review of SNO data analyses and publications.
- Scintillator phase preparation:
  - Participate in the scintillator filling activities and the purity estimation analyses;
  - Improve the speed and efficiency of MonteCarlo simulations of various background components.

In addition, an important overaall goal was to install a SNO+ remote control room at LIP.

Achievements and responsibilities during the past year

Concerning the execution of the planned SNO+ activities for 2018, they were mostly achieved, only the plans related to scintillator fill are still pending. A major general milestone was the completion of the SNO+ LIP remote control room, from which we can now carry out SNO+ detector operator shifts.

Calibrations

Production of the second URM unit for the SNO+ calibration source insertion system at the Coimbra workshop was delayed and is not completed yet. We have participated in the main functionality tests of the first unit at SNOLAB, that have identified a couple of points for improvement.

We were responsible for the run plans of all the optical and neutron calibration scans, and have participated in the data-taking at SNOLAB, as well as in data analysis.

These resulted in measurements of the detector optical model parameters, and properties of neutron propagation.

Data-quality (DQ) and Run Selection (RS)

In 2018 the group was very active in DQ/RS in order to validate the data for the all the physics analyses and for the day-to-day analysis of backgrounds due to changing detector and water flow conditions. Automatization of the RS progressed, with the implementation of semi-automatic scripts and a new database and software platform for the fully automated process. This system is now undergoing tests.

Water Phase Analyses

We coordinated the Backgrounds group activities and regularly analyzed the water phase data, providing identification of internal and external background sources, as well as an understanding of the convection-driven mechanisms for radon movement in the detector. Once the radon-suppression cover gas systems was operational, we contributed to green-light the start of scintillator fill. This work also provided optimized cuts and a full characterization of the backgrounds for different time periods of the water phase physics data set. Together with the DQ/RS work, these were our main contributions to the first two SNO+ physics papers, now accepted for publication.

We coordinated the Antineutrino physics group, establishing with calibrations that the neutron detection efficiency in SNO+ is unprecedentedly high for an unloaded water Cherenkov detector (publication in preparation). This led us to prepare an antineutrino search in the water data, and we have focused on methods to process the coincidence event data, allowing the reconstruction of low energy events usually discarded.

Scintillator Phase developments

We have coordinated the development of analysis tools to measure the scintillator radiopurity with about 10 days of data and help to decide whether to continue filling or undergo further purification.

We have worked on Monte Carlo simulations, continuing the improvement of the reactor neutrino generator, but also implementing a variety of methods to speed up the simulations of signals and background.

Lines of work and objectives for next year

The more demanding aspects of our hardware tasks in SNO+ (building calibration equipment) are almost finished, and for our analysis service tasks the main tool development work (RS automation, optical calibration code) is also almost completed, so from 2019 on we can focus primarily on physics analyses. Until the purification plant issues are fully solved, SNO+ will continue taking data with the detector filled with water, with just the initial 25 cm of scintillator on top. Still, we expect these issues to be solved soon, and scintillator fill to resume. The specific planned activities are the following.

Calibrations

- Finalize the analysis of the neutron source data in the water phase and the corresponding publication.
- Finalize the complete analysis of the water phase optical data, including the external scan data, and inputs from the analysis of the external fiber data.
- Review and approve the plans for the cleaning and deployment of a low energy gamma source in the scintillator phase (design and construction of the encapsulation was approved last year).
- Conclude the construction of the second URM and ship it to SNOLAB.
- Review and approve the design of interface equipment still necessary for the scintillator phase calibrations, under preparation by the SNOLAB group.
- When the full set of interface equipment is ready, we will propose the run plans and participate in optical, neutron and gamma source deployments in the scintillator phase.

Data Quality and Run Selection

- Deploy the fully automated run selection framework to be tested during the scintillation fill.
- Contribute to regular Run Selection work for the continuing data taking.

Water Phase Analyses

- Carry out the search for antineutrino events in the water data, through the search for positron-neutron coincidences: the focus will be on estimating one of the major backgrounds, the alpha-n events due to ^{210}Po leaching from the acrylic vessel. If successful, this would be the first detection of reactor antineutrinos in an unloaded water Cherenkov detector.
- Use the more recent water data (late 2018), in which internal backgrounds were lower, to improve the constraints on external backgrounds. This is crucial for the DBD phase and would lead to a publication.

Scintillator Phase Preparation and Analysis

- Lead and carry out analyses aiming to determine the purity level of the first ton-scale scintillator batches in the detector, as well as measuring the background level throughout the entire phase.
- Prepare and 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.

Continue to work on improvements to the speed and efficiency of the SNO+ Monte Carlo simulations.

Prepare the simulation and analysis tools for an analysis of the ^{7}Be solar neutrino signal in SNO+. 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, such as the decay of cosmogenic ^{11}C, an important background to some solar neutrino analyses.

Continue the preparatory work for the double-beta decay phase with sensitivities study as a function of cocktail purity, mitigation strategies, optics effects (PMT response, scintillator attenuation).

SNO Analyses

We expect to participate in the analysis of the hep solar neutrino flux with the full SNO data set.

DUNE

Lines of work and team organization

The group has started very recently its activity in DUNE. DUNE is a long baseline experiment, for which neutrino and anti-neutrino beams will be produced at FermiLab and detected 1300 km away at SURF, in large Liquid Argon (LAr) TPCs. The beam is expected in 2026, and the first detector installation in 2025. A prototype of a single phase (SP) LAr TPC took beam data and is now collecting cosmic rays at CERN; a double phase (liquid + gas) is under preparation also at CERN.

The lines of work, and the list of group members that will focus in each of them, is the following:

- DUNE Far detector calibration
  - Laser for LAr ionization (JM, FN, FB)
  - Pulsed Neutron Source (SA, VS, FB, AM)
  - Interface with DAQ (NB)
- protoDUNE prototypes at CERN
  - Operations: trigger and DAQ (NB)
  - Data analysis (FB, SA, GP, NB)

List of internal DUNE leadership responsibilities taken by group members: Calibration Consortium Leader (JM), protoDUNE-SP trigger coordinator (NB).

Achievements and responsibilities during the past year

We joined DUNE in May of 2018, so our participation was still limited. Nevertheless, we started to contribute to the following aspects:

- Laser calibration of the far detector: estimation of laser coverage goals based on DUNE physics fiducial volume precision requirements; conceptual study for an alternative mirror positioning system with better coverage; writing of TDR; formation and leadership of new Calibration Consortium.
- Pulsed Neutron Source Calibration: preparation of software tools for simulation studies of the design of the moderator and energy filter system.
- protoDUNE analysis: estimation of space-charge effects due to ^{39}Ar and cosmics.

Lines of work and objectives for next year

The specific planned activities are the following.

Calibrations

- Contribute to the design of the DUNE far detector laser calibration system:
  - Estimate the achievable precision and coverage of a system based primarily in designs implemented in other LAr experiments like microBoone and SBND.
  - Propose improvements to those systems, namely at the level of achieving the best possible coverage in a far bigger detector, with alternative mirror positioning systems.
  - Propose an implementation for the laser/DAQ interface that can minimize the volume of data and maximize Supernova livetime.
- Contribute to the design of the DUNE far detector pulsed neutron calibration system:
  - Optimize the design of the neutron moderator and filter through Monte Carlo simulations.
  - Evaluate adequate positioning of source in cryostat by simulating propagation of neutrons in the LAr TPC.
  - Contribute to the data analysis of an auxiliary experiment at Los Alamos to measure the attenuation length of 57 keV neutrons in Argon.

protoDUNE

- Analyse cosmic muon data, with a goal of studying electric field distortions due to space charge and other effects. Search for neutron signals in protoDUNE data.
- Contribute to the operation of the trigger and DAQ system, of the running Single Phase (SP) detector.
- Prepare the design of the calibration systems prototypes, to be installed and tested in protoDUNE in the 2021 run.

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: water and partial scintillator fill during 2019, pure unloaded scintillator following that, and Te-loaded scintillator from 2020 onwards. This will allow for a diverse range of physics topics, from reactor antineutrino oscillations, solar neutrino physics, and the first DBD search analyses. Ongoing re-analyses of SNO data are also expected to lead to physics publications in the near future.

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 cosmics data. We will focus on designing the far detector calibration systems using LAr ionization laser beams, to measure electric field distortions, and a pulsed neutron source, dedicated to the low energy response. Operations and data analysis of protoDUNE are also strategic goals for the longer-term development of an expertise in LAr detectors at LIP.

SWOT Analysis

Strengths

The main strength of the group resides in the diverse range of competences and 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

One weakness of the group is the absence of students at undergraduate and Master's level. The group is presently composed of six researchers, two PhD students and a graduated fellow, still a very “top-heavy” structure. This is a common situation at LIP, and our group is engaging with coordinated efforts to attract students at undergraduate and master level.

Threats

SNO+ is a high-risk, high-gain experiment: loading large quantities of very pure Tellurium in the liquid scintillator is a major technical challenge. Difficulties met while designing and installing the loading and purification plant can induce further delays to the schedule and compromise 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 needs to be gained. That gain could be compromised or delayed if we run into difficulties, financial or otherwise, with commitments, for instance in the production of the calibration system prototypes for protoDUNE.

Opportunities

The shift of SNO+ towards data-taking and physics analysis, that has been going on for more than a year, can potentially attract new students, since data analysis provides excellent opportunities for Master's theses. With the start of the scintillator phase, in addition to double-beta-decay physics, new topics will be explored.

Also, the new participation in DUNE, that started in May 2018, will balance the current participation in the analysis of SNO+ with a focus on design and construction of future detectors that will have a very strong role in neutrino physics in the next decade.

SNO+ / DUNE

Publications

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

- A. Sörensen, S. Hans, A.R. Junghans, B.v. Krosigk, T. Kögler, V. Lozza, A. Wagner, M. Yeh, K. Zuber: "Temperature quenching in LAB based liquid scintillator", Eur.Phys.J. C78 (2018) 9
- SNO collaboration: "Tests of Lorentz invariance at the Sudbury Neutrino Observatory", Phys.Rev. D98 (2018) 112013

5 International Conference Proceedings

- *"Reactor Antineutrinos in SNO+"*, S. Nae on behalf of the SNO+ Collaboration, published in Proceedings of student poster session of the VII International Pontecorvo Neutrino Physics School (Prague, Czech Republic, August 20 - September 1, 2017), edited by F. Simkovic, - Dubna: JINR, ISBN 978-5-9530-0484-8
- *"Optical Calibration of the SNO+ Detector"*, A.S. Inácio on behalf of the SNO+ Collaboration, published in Proceedings of student poster session of the VII International Pontecorvo Neutrino Physics School (Prague, Czech Republic, August 20 - September 1, 2017), edited by F. Simkovic, - Dubna: JINR, ISBN 978-5-9530-0484-8
- *"SNO"*, J. Maneira (on behalf of the SNO Collaboration), Proceedings of the XVII International Workshop on Neutrino Telescopes. March 2017, Venice, Italy
- *"Calibration of the SNO+ Detector with a Light Diffusing Source in the Water Phase"*, A. S. Inácio et. al. on behalf of the SNO+ Collaboration, Proceedings of the XXVIII International Conference on Neutrino Physics and Astrophysics
- *"AmBe source calibration in the SNO+ water phase"*, Y. Liu on behalf of the SNO+ Collaboration, Proceedings of the XXVIII International Conference on Neutrino Physics and Astrophysics

3 National Conference Proceedings

- *"From SNO to SNO+ and the search for neutrino masses"*, J. Maneira on behalf of the SNO+ Collaboration, Published in Livro de Atas da 20.ª Conferência Nacional de Física e 26.º Encontro Ibérico para o Ensino da Física, FÍSICA 2016.
- *"Reactor neutrino oscillations with the SNO+ detector"*, Stefan Nae on behalf of the SNO+ Collaboration, Published in Livro de Atas da 20.ª Conferência Nacional de Física e 26.º Encontro Ibérico para o Ensino da Física, FÍSICA 2016.
- *"Measuring oscillations with different neutrino sources"*, S. Andringa, Published in Livro de Atas da 20.ª Conferência Nacional de Física e 26.º Encontro Ibérico para o Ensino da Física, FÍSICA 2016.

Presentations

3 Oral presentations in international conferences

- Gersende Prior: *"Commissioning and prospects of the SNO+ experiment"*, 2018-02-22, Lake Louise Winter Institute 2018, Lake Louise, Alberta, Canada
- Valentina Lozza: *"The SNO+ Experiment"*, 2018-06-12, 5th International Solar Neutrino Conference, Dresden, Germany
- Sofia Andringa: *"SNO+ present results and prospects"*, 2018-06-22, BEACH 2018 - XIII International Conference on Beauty, Charm and Hyperon Hadrons, Peniche, Portugal

1 Presentations in national conferences

- Sofia Andringa: *"Particle Observatories - Participação Portuguesa em projectos de astroparticulas: SNO+, Pierre Auger, LZ, AMS"*, 2018-07-03, CIÊNCIA 2018, Lisboa

2 Poster presentations in international conferences

- Ana Sofia Inácio: *"Calibration of the SNO+ Detector with a Light Diffusing Source in the Water Phase"*, 2018-06-05, Neutrino 2018 - XXVIII International Conference on Neutrino Physics and Astrophysics, Heidelberg, Germany
- Yan Liu: *"AmBe source calibration in the SNO+ water phase"*, 2018-06-05, Neutrino 2018 - XXVIII International Conference on Neutrino Physics and Astrophysics, Heidelberg, Germany

1 Seminars

- Gersende Prior: *"The SNO+ experiment: status and prospects"*, 2018-04-11, Physics Department Seminars, FCUL, Lisboa

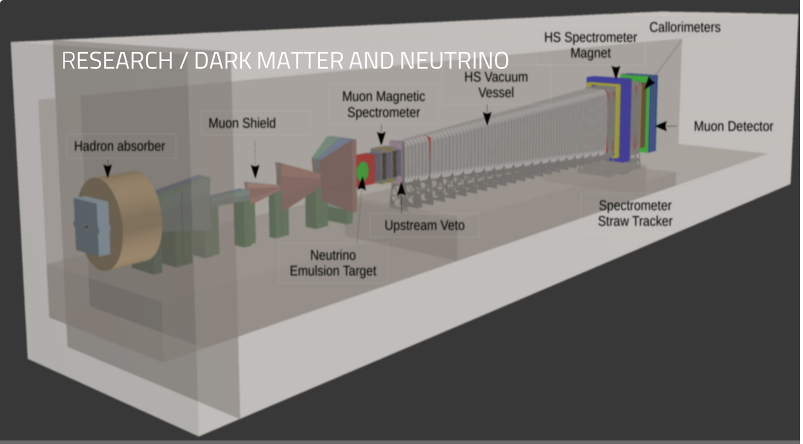
Theses

2 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)

1 Master

- Glória Pereira: *"The impact of electric field distortion on CP violation studies: study of space charge effects on protoDUNE "*, 2018-10-03 , (ongoing)



SHiP

Search for Hidden Particles

Principal Investigator:
Alberto Blanco (40)

2 ***Researcher(s):***
Celso Franco (15), Paulo Fonte (35)

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 (*)

Total FTE:
2.0

(*) starting in 2019

Article(s) in international journals:
2 Indirect contribution
Collaboration meeting(s):
3 Oral presentation(s)

Executive summary

The discovery of the Higgs boson at LHC in 2012 made the Standard Model of elementary particles complete but the quest for new particles has however not ended. Several well-established observational phenomena – neutrino masses and oscillations, dark matter, and baryon asymmetry of the Universe – cannot be explained with known particles alone and clearly indicate that New Physics should exist. The fact that no convincing signs of new particles have been found so far suggests that they are either heavier than the reach of the present days accelerators or interact very weakly.

The SHiP experiment is designed to search for extremely feebly interacting, relatively light and long-lived particles, at the intensity frontier. The SHiP experiment can also probe the existence of Light Dark Matter through the observation of its scattering on electrons and nuclei in its neutrino detector material. In the region from a few MeV/c2 to 200 MeV/c2 the SHiP sensitivity reaches below the limit which gives the correct relic abundance of dark matter. SHiP is being proposed as a discovery experiment but it also includes a rich program of tau neutrino physics and measurements on neutrino-induced charm production.

The LIP-SHiP group was created in 2018 with the aim of developing the timing detector of the SHiP spectrometer based on RPCs. In addition to the RPC group members, other LIP researchers joined the group with the goal of contributing to the physics analyses. Group members are formally part of the SHiP experiment (a recognized CERN experiment, but not yet approved). For the moment most of the work involves the development of hardware and simulation software. The RPC is presently being included in the official software, FairSHiP, to study its impact on the various physics channels. The experiment is expected to be approved in 2020 and start taking data in 2026.

The LIP-SHiP group is still embryonic (as it should be at such an early stage) but the goal is to grow progressively in the analysis branch. Presently, the experiment is receiving a large amount of attention from the particle physics community as it is demonstrated by the number of citations of the SHiP physics paper (over 300) and the size of the collaboration (more than 250 members from 53 institutes in 20 countries). The group is financially supported by an FCT "fundo CERN" project and by the RPC R&D group.

Sources of funding

Code	Amount	Dates	Description
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

An important element of the SHiP spectrometer is the timing detector, a detector with 50 m² and capable of measuring the crossing time of particles with an accuracy better than 100 ps and an efficiency as high as possible. The LIP-SHiP group is proposing for this detector an alternative option (to the traditional scintillator technology which is the base solution) based on the timing Resistive Plate Chamber (tRPC) technology, which uses a novel concept for the construction of the RPC gaps.

The group will also contribute to the development of Physics simulations with the goal of maximising the rejection of backgrounds in the Hidden Sector spectrometer, and to optimise the reconstruction of various analysis channels in the Neutrino spectrometer.

In a natural way, the hardware activities are driven by the Coimbra branch (where the Detector Lab and Mechanical Workshop are located) while the software and analyses part are lead by Lisbon branch.

Achievements and responsibilities during the past year

A prototype module for the SHiP timing detector was designed and built in close collaboration with the Detector Laboratory (DL) and the Mechanical workshop (MW). It uses a novel concept on the construction of RPCs, based on the ideia of the RPC sensitive volume. With this approach, two delicate aspects of an RPC, the gas volume and the High Voltage (HV) insulation, are confined inside a permanent sealed plastic box, decoupling it from the rest, namely, the pick up electrodes, located on top and bottom of the sensitive volume. The main advantages of this sensitive volume are: versatility, the same volume construction can be coupled to different readout electrodes; ease of construction, can be constructed easily and at low cost in the scale of 1 to 2 m² and the complete gas tightness of the plastic box allows a low gas flux operation. The module is composed of two identical sensitive modules of six gaps of 0.3 mm, read out by a pick-up electrode located between the modules and equipped with 1600x30 mm² copper strips, covering an area of 1550x1250 mm² (~2 m²). This technology together with the associated system (FEE, DAQ, LV and HV) can be directly extrapolated to the SHiP timing detector size.

After validation with cosmic rays in the Coimbra DL, the prototype was exposed to negative pions of -8 GeV on October 2018 at CERN's T9 test beam area. The response of the systems has been tested with the help of four timing scintillators with a timing accuracy of 30 ps, used as a reference. The almost 2 m² active area has been scanned on different positions in order to obtain efficiency and timing accuracy. The results show an average efficiency and timing accuracy of 98% and 54 ps without noticeable dependence on position over the entire area. Preliminary results were presented in the last collaboration meeting and full data analysis is under way.

The tested prototype is being included in the official software of the experiment, FairSHiP, as a base for the SHiP timing detector, in order to study its impact on the various physics channels, with special emphasis on the amount of matter that this technology introduces and the superior timing accuracy (when compared to scintillators).

Lines of work and objectives for next year

For 2019, the plan is the following:

- Finalize the analysis of the 2018 test beam data and present results to the collaboration (preliminary results have already been presented) 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 purpose of this RPC is to serve as a Veto detector for neutrino-induced backgrounds in the Hidden Sector spectrometer. A preliminary solution was already presented to the collaboration and a study of its impact in the various Physics analyses is foreseen for 2019.
- Start a close collaboration with the SHiP neutrino group with the goal of optimising the neutrino spectrometer for the various physics channels. Relevant contributions can be provided with the help of machine learning techniques.

Medium-term (3-5 years) prospects

Recently the group increased the number of FTEs by 1.4. Celso Franco was elected the new PI of SHiP and two new members joind the group: an experienced researcher, Nuno Leonardo, and a master student, Guilherme Soares. Up to now, with the available resources, a first RPC module was designed, constructed and tested at CERN, to evaluate the construction feasibility of the timing detector based on this technology. Both the timing and veto detectors, based on RPCs, are being implemented in the simulation software (FairShip) to study their impact on the identification of signals and rejection of backgrounds in the Hidden Sector spectrometer. For the upcoming years the plan is the following:

- The group was already able to attract a Master student, Guilherme Soares, to do his Thesis in SHiP. The work will involve the implementation of a specific Axion-Like Particle (ALP) channel in FairShip, ALP -> gamma gamma (good inflaton candidate whose decay can mimic the reheating phase of the early Universe), and a study of the separation of backgrounds from ALPs, Heavy Neutral Leptons, Dark Photons and light Neutralinos. The studant may also use machine learning algorithms to maximise the efficiency and purity of the Hidden Particles selection.

- After approval of the experiment, which is foreseen to happen after the spring of 2020, the group intends to attract one or two researchers to the analysis group, in addition to Celso and Nuno, and at least 2 students. The goal is to have at least one PhD student in 2 years from now. Nevertheless, 2 PhD projects are now being submitted to IDPASC. In order to facilitate the integration of students in the group a SHiP project was submitted to the next "Estágios de Verão". The group was already contacted by a student wanting to collaborate in the project. The work to be done in the next 2/3 years will mainly involve the development of Physics simulations with the goal of optimising the SHiP spectrometer to maximise the rejection of backgrounds in the Hidden Sector spectrometer, and also to optimise the reconstruction of the various analysis channels in the Neutrino spectrometer. In parallel, the RPC group will continue the prototyping of both the timing and veto detectors during 2019. This scenario will be feasible with a minimum of 60 k€. The resources would be shared between the hardware developments and the payment of a few student grants.

- In case of SHiP approval the group would need to collect at least 500 k€, spread over a period of 5 years (starting in 2021), to construct the timing detector for the Hidden Sector spectrometer (in case our proposal is the selected one). Concerning the RPC to be included in the Neutrino spectrometer, for the moment our group is the only candidate. The construction of such a detector would involve a significantly smaller amount of resources (on the order of 100-150 k€). The OM-DL infrastructures would have an intensive use during this period. By this time the analysis group from LIP should be deeply involved in the various analysis groups of the collaboration (with a large fraction of FTEs dedicated to the activity).

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 RPC detectors technology.
- The remaining part of the team has strong competences in DIS physics and also in the exploration of the Hidden Sector via open-charm and open-beauty.
- The team has very good skills in machine learning techniques, a plus for the optimisation of the SHiP spectrometer.
- The group is being able to attract students: one master student is already part of the group and another student already demonstrated a strong will of collaborating with us in a near future.

Weaknesses

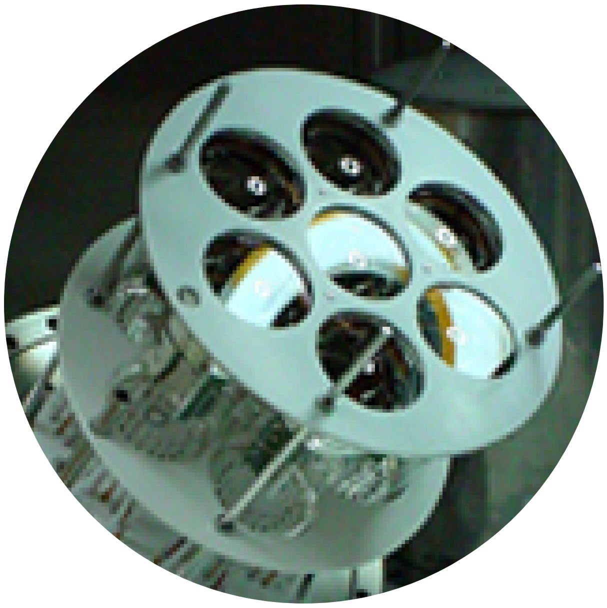
- For the moment, the limited manpower and financial capability for the proposed tasks.

Opportunities

- We believe that SHiP will be a major particle physics experiment, with the potential to make a breakthrough in the field. To integrate this project from the beginning is thus an opportunity for LIP. Currently we are an embryonic group but we feel that we are capable of developing an important role within the collaboration. Moreover, this project has all the conditions to attract students: it is a discovery experiment (allways exciting) and, at the same time, it has a unique program of tau neutrino physics (the less known particle of the standard model).

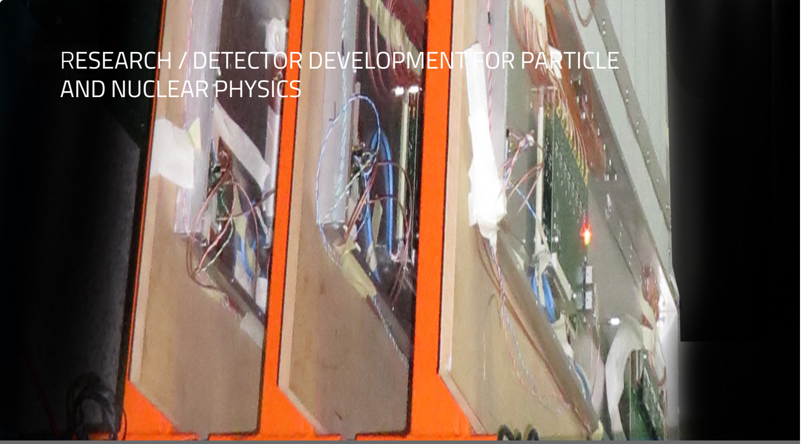
Threats

- The SHiP experiment is not yet approved as a CERN project.
- RPC technology is not yet approved for the construction of the timing detector of the Hidden Sector Spectrometer. However, our group is the only candidate to build the timing detector of the neutrino spectrometer.
- Available financial resources may not be enough for the construction of the entire detector for the Hidden Sector spectrometer.



[Detector development for particle and nuclear physics]

RPC R&D
Neutron Detectors
Gaseous Detectors R&D
Liquid Xenon R&D



RPC R&D

Resistive Plate Chambers (RPC)

Principal Investigator:
Alberto Blanco (15)

5 *Researcher(s):*
Miguel Couceiro (10), Paulo Crespo (25), Paulo Fonte (40), Rui Marques (30), Susete Fetal (20)

2 *Technician(s):*
João Saraiva (65), Luís Lopes (50)

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

Total FTE:
3.5

Article(s) in international journals:
1 Direct contribution
International conference(s):
1 Oral presentation(s)
International meeting(s):
1 Oral presentation(s)
National conference(s):
1 Oral presentation(s)
Collaboration meeting(s):
2 Oral presentation(s)

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 multihit capability in dense arrays, the use of ceramic materials and warm glass for enhanced count-rate capability, application of RPCs to animal and human Positron Emission Tomography (RPC-PET), simultaneous high-resolution measurement of positions and times (TOFtracker), very low maintenance, environmentally robust, RPCs for deployment in remote locations and large area fast-neutron TOF 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.

In close collaboration with the detector lab we also design and produce detector-support electronics, such as front-end amplifiers and high-voltage power supplies. We participated currently, in AIDA2020. In addition, the group, cooperates with several other LIP groups: Neutron Detectors, AUGER, LATTES, HADES and SHiP, supporting their RPC-related activities. See the specific reports for further details. The leadership of the group was transferred from P. Fonte to A. Blanco in the middle of the year and the RPC-PET group was reintegrated into the RPC R&D group.

Sources of funding

Code	Amount	Dates	Description
AIDA-2020	45.000 €	2015-06-01 / 2019-05-31	Advanced European Infrastructure for Detectors at Accelerators
STRATOS R&D	20.000 €	2019-01-01 / 2020-12-31	STRATOS R&D
STRATOS	80.000 €	2019-01-01 / 2020-12-31	STRATOS project

Total: 145.000 €

RPC R&D

Lines of work and team organization

The core RPC R&D group is rather small. Although a name is indicated in the following subprojects, there is not a strong segregation of responsibilities within the group. 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 (TOF-RPCs) 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. The group is developing this technology based on an innovative concept for the construction of RPCs, to be applied in the SHiP and HADES experiments (see specific reports). With this approach, RPCs can be constructed easily and at low cost in the scale of 1 to 2 m² with a performance that can reach values of 50 ps and 98% for timing accuracy and efficiency respectively. In combination with time, the precise simultaneously measurement of the particle position (TOF-Tracker) 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

- RPC-PET
  - Upgrade of the existing RPC-PET to a pre-commercial small-animal scanner.
- TOF & TOF-Tracking
  - Calibration of the 4-layer muon telescope for the HYDRONAV S.A company, as well as commissioning of the MASTER RIO telescope, both muon tomographs.
  - Construction and evaluation of the first prototype of a module of the RPC-TOF-FD/SHiP. Construction of four modules after validation.
- Autonomous RPCs for cosmic ray measurements
  - Finish the MARTA FCT/FAPESP production (40 RPC detectors in total), the integration at São Carlos, Brazil, and installation at the Auger site (this task is mainly done by the Detector Laboratory together with Mechanical Workshop staff).
  - R&D in the framework of LATTES, mainly in the operation of RPC at low pressure (high altitude).
  - Construction, test and deployment of the cosmic ray telescope for the Antarctica project.
  - Upgrade (trigger, monitor and HV system) of the TRAGALDABAS cosmic ray observatory and resuming of data taking.
- High rate RPCs
  - Finalize the data analysis of the gathered data during the test beam at CERN. This will be the outcome of the AIDA2020 EU project.

Achievements and responsibilities during the past year

- RPC-PET
  - A project for the construction of a Brain PET was submitted to the C2020, in cooperation with ICNAS-Produção and IPC institutes. In addition, a project in cooperation with GSI was submitted to the ATRACT call. During the year 111 mice examinations were carried out with the aim of supporting research at ICNAS (something that has, in part, slowed down the upgrade, due to the absence of time slots for this task). Anyhow, parts of the software that were developed for former DAQ were adapted to the new one and missing components have started to be developed. Steps have been taken to upgrade the detectors and mechanics to final pre-commercial device.

- TOF & TOF-Tracking
  - A project (STRATOS) for the construction of two cosmic ray telescopes for the monitoring of the stratosphere temperature was submitted by HYDRONAV in cooperation with LIP. The system (with reasonable timing and position capabilities) is a prototype for a future macro-scanner for cargo container scans. The project was recommended for funding.
  - The calibration of the 4-layer muon telescope for HYDRONAV, as well as the commissioning of the MASTER RIO telescope, were not done due to lack of human resources. Nonetheless, the first was completely functional/operative fulfilling the objectives of the project.
  - The construction and evaluation of the first prototype of a module of the RPC-TOF-FD/SHiP was concluded. After validation with cosmic rays in the Coimbra DL, the prototype was exposed to negative pions of -8 GeV on October 2018 at the CERN T9 test beam area. The results show an average efficiency and timing accuracy of 98% and 54 ps without noticeable dependence on position over the entire area. (see SHiP report for more information). The construction of the four modules of the RPC-TOF-FD is postponed to 2019 due to lack of resources in conjunction with the delay in deadlines.
- Autonomous RPCs for cosmic ray measurements
  - The MARTA FCT/FAPESP RPC production was almost completed (it will be early in 2019). The integration in São Carlos and installation at the Auger site has accumulated some delay and will be done in 2019 (see Auger report for more information).
  - The RPC test at low pressure (high altitude) for LATTES was postponed, waiting for the Mechanical Workshop to deliver the sub-pressure box ordered.
  - The construction, test and deployment on the Sarmiento de Gamboa vessel of the TRISTAN cosmic ray telescope was accomplished successfully. First latitudinal survey, from Spain to Antarctica, was finalized and preliminary data are available. Full data analysis is under way.
  - The TRAGALDABAS upgrade (trigger, monitoring and HV system) was finalize successfully and data taking resumed.
  - The design of a portable cosmic ray telescope to be used in muon tomography was started, in collaboration with the LIP Auger group and a group from the University of Évora.
- High rate RPCs
  - Analysis of the data gathered during the test beam at CERN for testing high rate RPCs was finished and an internal note delivered (outcome of the AIDA2020 EU project).

Lines of work and objectives for next year

Any opportunity of funding in the framework of our activities will be pursued. In 2019, a new FCT/PTDC call will open. In the meanwhile, we are still waiting for the decision on open calls, which might modify the plan outlined here.

- Finalize the upgrade of the existing RPC-PET to a pre-commercial small-animal scanner and continue supporting the PET examinations at ICNAS.
- Design, construct and test the first station of STRATOS.
- 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.
- 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 (see Auger group report for more information).
- Perform the low pressure (high altitude) development/measurements for LATTES.
- 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.
- Continue the development of the sealed RPC chambers.

Medium-term (3-5 years) prospects

First of all, it is important to take into account our funding situation. The last time the group had a substantial regular project approved was in 2012; since then we have been asking for funding in all available calls (3-4/year), with small and discouraging results. In this scenario, it is extremely difficult to define a clear plan: research directions could change depending on the approved projects. For instance, our recent planing has been substantially modified by the approval of the STRATOS project (fortunately with substantial resources) and by the approval of the interesting SHIP project (with rvery small funding). As a consequence, the plan we construct can be strongly modified by the approved projects, which are not necessarily the more interesting ones. Taking this into account our plans for the next years are: Develop the brain PET proposed on the C2020 project or a fully commercial pre-clinical PET. Design, prototype and construct the timing detector for SHiP (if this is approved) and a full detector for transmission tomography. Collaborate with the MARTA and LATTES (towards RPCs operated at high altitude) projects and secure the operation of TRISTAN. In addition, a transversal activity, the R&D on sealed and autonomous RPCs will continue.

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

- Structurally, there is a limited capability to cope with variable demands on detector production, which in an optimistic scenario may limit our throughput capacity.
- The lack of base funding makes the group to be dispersed among different projects.

Opportunities

- The team was reinforced recently with the arrival of a new physicist under a technical contract.
- We believe to have or being about to have very competitive detectors for the application "markets": animal RPC-PET, muon tomography, cosmic ray physics and HEP.
- The human RPC-PET application requires a longer and more demanding development, along with funding of the order of millions, but it is potentially hugely interesting.
- We are proposing to the new SHiP collaboration at CERN to contribute to the experiment with an RPC timing detector.

Threats

- Hostile funding environment.
- In the long term, the excessive maturation of the team members will become a determinant factor.

RPC R&D

Publications

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

- *"The trigger system of a large area RPC TOF-tracker muon telescope"*, F. Clemêncio, A. Blanco, N. Carolino and C. Loureiro, JINST 13 T08001 (2018)

Presentations

1 Oral presentations in international conferences

- Alberto Blanco: *"ORCA: Future Antarctic Cosmic Ray Observatory"*, 2018-04-02, EGU General Assembly Conference, Viena, Austria

1 Oral presentations in international meetings

- Paulo Fonte: *"Simulations of discharge phenomena"*, 2018-06-21, RD51 topical workshop on "MPGD Stability", Technical University of Munich, Garching, Germany

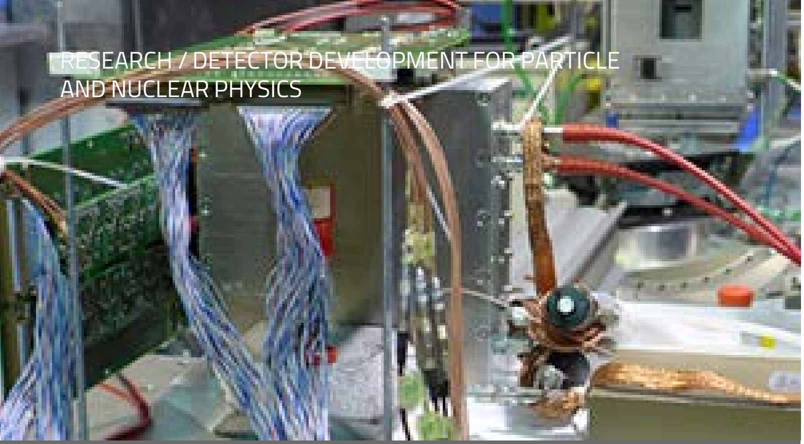
1 Presentations in national conferences

- Paulo Fonte: *"Animal and human RPC-PET"*, 2018-03-23, Future Directions in Nuclear Sciences Applied to Health, Coimbra, Portugal

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)



NEUTRON DETECTORS

Principal Investigator:
Luís Margato (85)

3 *Researcher(s):*
Alberto Blanco (5), Andrey Morozov (25), Paulo Fonte (20)

1 *External collaborator(s):*
Alessio Mangiarotti

Total FTE:
1.3

Article(s) in international journals:
1 Direct contribution
International conference(s):
4 Oral presentation(s)
National conference(s):
1 Oral presentation(s)

Executive summary

For more than ten years our group is working on development of neutron detectors in partnership with world leading detector groups from large-scale neutron facilities in Europe such as ILL (Institut Laue-Langevin), ISIS (Neutron and Muon Source) and TUM-FRMII (Forschungs-Neutronenquelle Heinz Maier-Leibnitz). A continuous and fruitful collaboration has been pursued throughout successive EU-projects (NMI3-FP6, NMI3-FP7), and which is currently being continued within the SINE2020 consortium - Science and Innovation with Neutrons in Europe in 2020 (EU project 654000).

Our main goal is to develop a novel type of PSND (position-sensitive neutron detector) based on 10B-RPCs (10B-lined Resistive Plate Chambers) recently introduced by the group. Our studies demonstrate that 10B-RPCs can offer a unique combination of characteristics: very high spatial (FWHM < 250 μm) and temporal (sub-nanosecond) resolution, high detection efficiency (>50%), strong design modularity, good scalability, robustness and low price per unit area. The sub-nanosecond timing resolution intrinsic to RPCs and the short (~1 ns) flight time of neutrons through the 10B4C converter layer (~1 μm thick) make 10B-RPCs particularly well suited for applications requiring PSNDs capable of providing TOF information, such as, e.g., energy-resolved neutron imaging at pulsed neutron sources including ISIS and ESS (European Spallation Source). To make 10B-RPC based PSNDs a competitive detection technology for future applications at neutron facilities, homeland security and industry, the near-future objectives are to enhance the already demonstrated counting rate (~103 Hz/cm2) by two orders of magnitude and to demonstrate a capability to operate with neutron/gamma ray rejection better than 105.

The secondary goal is to continue the development of PSNDs based on solid scintillators performed in collaboration with leading institutes in the field (FZ Julich, ISIS and ILL). During the last year very encouraging results were obtained at ILL with a detector prototype, built at LIP, consisting of a GS20 scintillator (loaded with 6Li) and a SiPM array. Auto-calibration capability was demonstrated and a spatial resolution of ≈0.6 mm FWHM was achieved by applying a statistical reconstruction method to compute the event position. Our international partners are particularly interested in the unique know-how of the adaptive reconstruction of the detector light response developed in LIP and on our experience in detector optimization using the ANTS2 toolkit (developed by a member of our group).

Sources of funding

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

Total: 161.913 €

Neutron Detectors

Lines of work and team organization

The team is constituted by four researchers having an extensive knowledge in the development of detectors for particle and nuclear physics. Andrey Morozov is working on the MC simulations (ANTS2 and GEANT4), optimization of the detector prototype configurations and position reconstruction techniques. Alberto Blanco is assisting mainly in ^{10}B-RPCs prototype design, readout electronics (FEE and DAQ system) and prototype testing on neutron beam lines. Paulo Fonte is contributing with his know-how in the physics of RPC detectors and assisting in the prototype design. Luís Margato is coordinating the group, participating in all the research activities.

The group has great contribution from the ESS detector coatings group with the development of the ^{10}B neutron converters and its deposition on RPC electrodes and from the TUM-FRMII neutron detectors group with prototype testing on a neutron beamline.

The group has also the support of the LIP's Detector Laboratory (DL) and of the Mechanical Workshop (MW) in the manufacturing of detector components.

The group activities are being developed mainly within SINE2020 where Luís Margato coordinates the activity "Resistive plate chambers development for thermal neutron detectors", which aims to assess the potential of ^{10}B- RPCs for neutron scattering science (NSS) and for other potential applications, such as, e.g. neutron imaging and homeland security.

Increase of the ^{10}B-RPCs counting rate capability by two orders of magnitude (relatively to the preliminary results) and decrease of the gamma ray sensitivity to the level of 10^{-5} are the two most challenging objectives to be tackled by the group.

The lines of work are organized as follows:

^{10}B-RPCs based PSNDs

This line of work is dedicated to the development of ^{10}B-RPC based PSNDs, focusing applications which require cutting-edge performance: accurate positioning (~100 μm) and timing (< 1 μs), high detection efficiency (> 50%), low gamma sensitivity (< 10^{-5}) and a counting rate > 10^5 Hz/cm^2. The following tasks were established:

- Detector design and performance optimization based on simulations with GEANT4 and ANTS2 toolkits.
- Evaluation of candidate materials for the RPC electrodes in terms of, e.g.: surface and bulk resistivity, neutron scattering, sensitivity to gamma rays, susceptibility to activation by neutrons.
- Optimization of ^{10}B neutron converters (ESS+LIP).
- Detector prototyping and evaluation in neutron beam at our partner facilities, e.g. TUM-FRMII, ILL or ISIS.
- 3D-readout and development of event reconstruction techniques.
- Basic studies, e.g. working gas optimization and study of the pulse shape of minimum ionizing particles (MIPs) and highly ionising particles (HIPs) events.

PSNDs based on Inorganic/ Organic scintillators

This line is dedicated to the common effort with several leading institutes in the field (FZ Julich and ISIS) to develop cutting-edge PSNDs based on solid scintillators, with our contribution focused on the improvement of spatial resolution (~0.5 mm), reduction of the gamma ray sensitivity based on introduction of pulse shape discrimination and application of the auto-calibration techniques allowing to establish the light response of the detector based on flood field irradiation.

Stated objectives for past year

During the last year and aligned with the SINE2020 – WP9 (Instrumentation-Detectors) goals our main objectives were:

- Carrying out MC simulations of a PSND prototype with a multilayer architecture by means of ANTS2 toolkit developed at LIP with the upgraded transport model for thermal neutrons.
- Detector design and prototyping.
- Detailed analysis of the experimental data recorded with the multilayer ^{10}B- RPC detector prototype in a test run with a neutron beam at TUM-FRMII.
- Study of the sensitivity of ^{10}B-RPCs to gamma-rays with ^{22}Na and ^{60}Co radioactive sources.

Achievements and responsibilities during the past year

1. ANTS2 toolkit was upgraded to include coherent neutron scattering by implementing the NCrystal library (X. X. Cai and T. Kittelmann, ESS).
2. MC Simulations were performed for different detector models. The effect of various parameters of the detector design on the performance (e.g. detection efficiency and spatial resolution) was studied.
   - A paper reporting the main results of this Monte Carlo simulation study was submitted to the Journal of Instrumentation (JINST) in 2018 and was accepted for publication (L.M.S. Margato and A. Morozov 2018 JINST 13 P08007).

3. An analysis of the neutron absorption and scattering in the detector materials (e.g. Glass, Al, Kapton, Cu, 10B4C and Freon-r134a) and of their impact on the detector response was performed by means of simulations with ANTS2.

4. A multi-variable optimization for ^{10}B-RPCs with a multilayer architecture was implemented in ANTS2 in order to find the optimal combination of the detector parameters (e.g. the number of RPCs forming the stack and the $^{10}B_4C$ thickness for each layer) leading to the optimal detector performance in terms of the counting rate and the detection efficiency. The results suggest that an improvement of the counting rate capability of at least an order of magnitude is possible without compromising the overall detection efficiency.

- An oral communication entitled "Design optimization and image reconstruction for position sensitive thermal neutron detectors with ANTS2 toolkit", reporting this simulation results, was presented at the International Workshop on Position Sensitive Neutron Detectors (PSND 2018) in Jülich (GE).

5. Concerning the multigap RPC (MRPC) configuration option for PSNDs, the ESS detector coatings group further investigated the improvement of $^{10}B_4C$ coatings resistivity. Despite a great effort, the maximum surface resistivity of $^{10}B_4C$ coatings, deposited by DC-magnetron sputtering on glass, remains too low (~ 10^6 ohm/sqr) for the MRPCs. As we have already reported, to avoid the shielding of the induction of signals in the pickup electrodes it must be increased above 10^7 ohm/sqr.

6. A MRPC (5 x gas-gaps) prototype with float glass electrodes coated on one side with a 1 µm thick layer of $^{10}B_4C$ (deposited at ESS) was built at LIP. The tests in a neutron beam at TUM-FRM II showed poor spatial resolution. It was also observed the spread of the induction signals to almost the entire active area of the detector, which explains the inability to accurately determine the position. To move forward with the MRPC configuration the surface resistivity of the ^{10}B neutron converters has to be increased significantly (> 10^7 ohm/sqr), which does not seem to be achievable soon.

7. Detailed analysis of the experimental data recorded with the multilayer ^{10}B-RPC prototype (20 layers of $^{10}B_4C$, 95% enriched in ^{10}B) in a test run with a neutron beam was performed. The detection efficiency for each one of the ^{10}B-RPCs in the stack was computed and showed to be in a good agreement with the values predicted by the ANTS2 simulations taking into account the events lost by neutron scattering and absorption in materials. An overall detection efficiency of > 50% was confirmed. The non-linearity in the reconstructed positions due to the discreteness of the pickup electrodes and the intrinsic distortions of the GoG (Center of Gravity) algorithm was examined. To minimize these effects different methods are being considered, e.g. a look-up table (LUT) obtained from a calibration dataset with a fine step scan or by using more advanced statistical reconstruction methods.

- An oral communication entitled "Status of the ongoing studies of B-10 RPCs for position-sensitive neutron detectors", reporting the main results obtained with a multilayer ^{10}B-RPCs prototype, was presented at the International Workshop on Position Sensitive Neutron Detectors (PSND 2018) in Jülich (GE).

8. A dedicated setup for the characterization of the sensitivity of the ^{10}B-RPCs to gamma-rays with ^{60}Co and ^{22}Na radioactive sources was assembled.

- Measurement of the plateau of a ^{10}B double-gap RPC for cosmic muons (MIPs – Minimum Ionising Particles), with a telescope consisting of two plastic scintillator tiles, demonstrated a considerable shift (> 500 V) to the higher voltages in respect to the plateau for thermal neutrons.
- First measurement of the ^{10}B double-gap RPC sensitivity to gamma-rays was performed in the same range of voltages as for the plateau for thermal neutrons; as far as we know there is no published data on the characterization of the sensitivity of RPCs to gamma-rays in this range of voltages.
- For a ^{10}B double-gap RPC irradiated by a ^{22}Na source, the results suggest that for 0.511 MeV photons the gamma sensitivity can be as low as 10^{-6}. It was also observed that for gamma rays with higher energies the sensitivity increases. For example, keeping the same voltage on the RPC electrodes (2200 V) a gamma sensitivity of ~10^{-5} was measured for the 1.27 MeV photons from the ^{60}Co source.
- An oral communication entitled "Gamma Sensitivity of ^{10}B lined thin-gap RPCs for Neutron Detectors", reporting the main experimental results on gamma sensitivity, was presented at the 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference, in Sydney (AU).

Lines of work and objectives for next year

A high counting rate and low sensitivity to gamma-rays, along with high efficiency and high spatial and temporal resolution, are the most challenging requirements for the next generation of neutron detectors which have to be addressed. For instance, it should be noted that the expected flux of thermal neutron for ESS will go beyond 2 orders of magnitude of the highest value nowadays available at ISIS or ILL. Besides, new accelerator-based pulsed neutron sources also enable the time-of-flight (TOF) analysis technique, driving new neutron imaging modalities such as energy-selective and energy-dispersive neutron imaging requiring sub-millimeter spatial resolution and sub-microsecond time resolution.

We have already demonstrated that ^{10}B-RPCs based PSNDs can offer an outstanding performance in respect of the spatial / time resolution and a detection efficiency as good as other ^{3}He alternative detector technologies.

To complete the puzzle and give a full picture of the potential of ^{10}B-RPC, our main objective are now focused on: (1) boost the counting rate by a factor of 100 in relation to the results achieved with a single-gap 10B-RPC tested at FRMII reaching a value of at least 10^5 Hz/cm^2; (2) demonstrate that the sensitivity to gamma rays can be less than 10^{-5}.

To respond to a need expressed by our partners from FZ Jülich, ISIS and ILL, concerning the development of PSNDs based on neutron sensitive lithium glass (e.g**. GS20**) and new organic (e.g. EJ-270) scintillators coupled to SiPM or PMT arrays, as a second objective we intended to cooperate with them, contributing mainly with the LIP know-how on the simulation of this type of detectors, event position reconstruction and auto-calibration techniques.

With this in view the lines of work and objectives for next year are:

^{10}B-RPCs based PSNDs

- MC-simulations with ANTS2 and GEANT4 toolkits:

Detector design and performance optimization; optimization of the detector geometry and the material composition to increase the count rate and reduce sensitivity to gamma-rays.

- Evaluation of materials for the RPC electrodes favouring high counting rate; a list of candidate materials will be selected and evaluated in terms of the surface and bulk resistivity, neutron scattering and susceptibility to activation by neutrons.
- Optimization and deposition of ^{10}B neutron converters needed for the prototypes. To be performed in collaboration with the ESS detector coating group.
- Detector's prototyping:

With the cooperation of the DL (Detectors Laboratory) and MW (Mechanical Workshop) in LIP-Coimbra, ^{10}B-RPC prototypes will be constructed and interfaced to the read-out electronics; preliminary tests with laboratory neutron and gamma sources will be performed.

- Detector-prototype tests on a neutron beam at our partners' facilities (e.g. TUM-FRM II, ILL or ISIS).

PSNDs based on inorganic / organic scintillators

- Simulation (ANTS2) and optimization of compact PSNDs with inorganic / organic scintillators, coupled to SiPM or PMT arrays. One main objective is to establish the best set of parameters (e.g. scintillator thickness, light guide properties and photo-sensor arrangement) that optimizes the detector performance (e.g., detection efficiency, spatial resolution, counting rate and gamma sensitivity). As a result of this task, the optimal parameters for the detectors construction will be obtained.
- Collaboration with a group from FZ Jülich on the development of a compact neutron Anger camera targeting 13 x 13 cm^2 active area, 75% thermal neutron detection efficiency and 1 mm spatial resolution.

Medium-term (3-5 years) prospects

The research activities are currently financed by the SINE2020 consortium, until the end of September 2019. After this date there is no guarantee of external funding.

Despite the project submitted to the FCT call SAICT2017 has been ranked well above the average, it was not financed due to lack of funds.

Our group, together with ISIS and ESS, has submitted a join proposal "**High count rate RPC based neutron detectors with 3D position sensitivity - nRPC100K**", to the recent **CERN EU ATTRACT** call, a one year project with a total budget of 100 kEur (60 kEur for LIP). Results to be announced in March 2019.

While it may sound unrealistic to outline medium-term objectives, given the current context of uncertainty in external financing, we believe it will still be possible to ensure activities strategically important for LIP with a relatively modest level of funding.

The R&D effort for the development of the ^{10}B-RPCs detector technology, e.g. for high precision 3D-PSNDs and the inorganic / organic scintillator-based neutron compact cameras, for applications requiring high counting rates and/or with high gamma-ray background environments, is of paramount importance for LIP to strengthen synergies with the European-leading neutron facilities (ESS, ILL, ISIS and MLZ-FRMII) and maintain capacity in developing novel detectors and experimental techniques for frontline research.

Ensure the development of our R&D plan on neutron detectors also promotes the exchange of knowledge with the world-leading groups of this scientific area, which is crucial to maintain the high research standards to which LIP is committed. Moreover it is **strategic** for

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In the medium-term, we also aim to develop a fast neutron spectrometer for real-time measurements. This goal can become strategic for LIP considering the field of medical applications (e.g. real-time neutron dose monitoring in Hadron Therapy) or homeland security. This will contribute to broadening the LIP's portfolio of offers with direct benefits to society. We believe in the potential of this activity to attract external funding in future calls. Being at an embryonic stage, the level of funding required to support this activity is quite modest.

The group growth is crucial to fully meet the scientific goals. Its reinforcement with at least one researcher (1 FTE) is essential to boost the group activities and its scientific output. We also make an effort to attract students (MS and PhD) and contribute to the training of the next generation of scientists in this important field of research.

SWOT Analysis

Strengths

For over a decade we are involved in the detector R&D programmes in partnership with world leading detector groups from the large-scale neutron facilities such as ILL, ISIS, TUM-FRM II, and more recently ESS.

The team members have accumulated an extended knowledge with the neutron detectors physics, their requirements and major challenges, as well as in Monte-Carlo simulations, detector design, detector construction and tests in neutron beamlines.

It is noteworthy that the optical readout of GEMs and the GSPC type detector for neutron imaging, and more recently the ^{10}B-RPCs based PSNDs are all detector concepts pioneered at LIP.

The group has access both to the DL and MW in Coimbra, with capability for the production of complex components needed to construct the detector prototypes.

The group has well-established ties with its international partners, which provides access to neutron facilities and fosters new EU funding opportunities.

Weaknesses

The current manpower is not sufficient to fully meet the group's ambition, compromising the achievement of the established goals within an acceptable time frame.

Lack of funding for MS and PhD grants to attract students.

Opportunities

ESS, currently under construction in Lund, Sweden, will be the world's most powerful pulsed neutron source. Due to the ESS strategic decision not to consider ^{3}He-based detectors (golden standard in neutron scattering science) in the design of its suite of instruments, presents huge challenges for the development of new type of detectors with cutting edge performance and high reliability. A new generation of neutron detection technologies has to be developed and refined during the next decades. This opens also the opportunity for the group to participate and contribute with their know-how to this endeavour.

In the framework of the collaboration with our partners, there are also plenty of opportunities for training of MS and PhD students related to the development of instrumentation for neutron scattering science.

Threats

The grant of the group coordinator is currently funded by SINE2020 and it ends on September 30, 2019.

The group research activities are currently financed with the funds from the SINE2020 consortium until the end of September 2019. After this date there is no guarantee of external funding.

Publications

1 Articles in international journals

(with direct contribution from the team)

- *"Boron-10 lined RPCs for sub-millimeter resolution thermal neutron detectors: conceptual design and performance considerations"*, L.M.S. Margato and A. Morozov, 2018 JINST 13 P08007

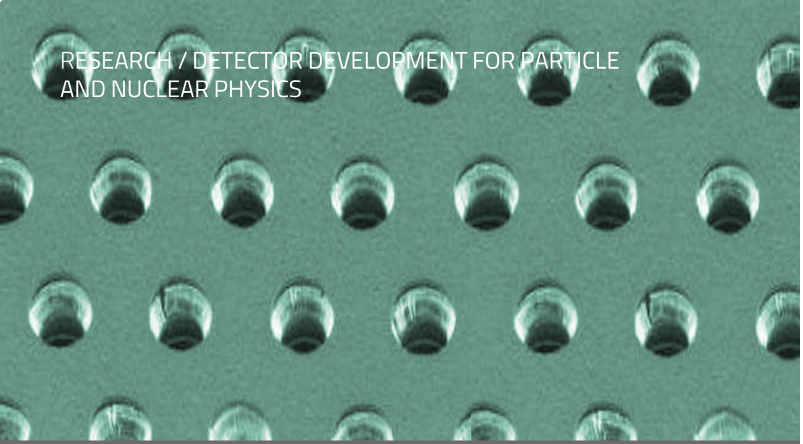
Presentations

4 Oral presentations in international conferences

- Luís Margato: *"Neutron imaging with 10B4C-lined thin-gap RPCs: A multilayered architecture for high detection efficiency"*, 2018-02-23, XIV Workshop on Resistive Plate Chambers and related detectors (RPC2018), Puerto Vallarta, Mexico
- Luís Margato: *"Status of the ongoing studies of 10B-RPCs for position-sensitive neutron detectors"*, 2018-05-16, PSND 2018 - International Workshop on Position Sensitive Neutron Detectors, Jülich, Germany
- Andrey Morozov: *"Design optimization and image reconstruction for position sensitive thermal neutron detectors with ANTS2 toolkit"*, 2018-05-16, PSND 2018 - International Workshop on Position Sensitive Neutron Detectors, Jülich, Germany
- Luís Margato: *"Gamma Sensitivity of 10B lined thin-gap RPCs for Neutron Detectors"*, 2018-11-14, 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference, ICC Sydney, Australia

1 Presentations in national conferences

- Luís Margato: *"Neutron Detectors"*, 2018-02-17, Jornadas do LIP 2018, Évora, Portugal



GASEOUS DETECTORS R&D

Principal Investigator:
Filomena Santos (42)

5 *Researcher(s):*
Carlos Conde (30), Filipa Borges (42), Jorge Maia (15), José Escada (70), João Barata (32)

2 *PhD Student(s):*
Alexandre Fonseca Trindade (60), André Cortez (54)

1 *Master Student(s):*
Miguel Santos (100)

Total FTE:
4.5

Article(s) in international journals:
8 Indirect contribution

Completed theses:
1 PhD

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, in the gases and their mixtures used as detector's fillings, with the aim of finding the more suitable one 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 these 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 Xe TPC to search for neutrinoless double beta decay and with the RD51 collaboration, that aims at developing new techniques for gaseous detectors with microstructures.

Sources of funding

Code	Amount	Dates	Description
PTDC/FIS-NUC/2525/2014	60.000 €	2016-05-01 / 2018-05-31	Detection of the Neutinoless Double Beta Decay in Xe-136: the NEXT Experiment
CERN/FIS-INS/0025/2017 - GD	35.000 €	2018-05-01 / 2020-04-30	Participation in RD51 - GD

Total: 95.000 €

Gaseous Detectors R&D

Lines of work and team organization

There are three main lines of work in our group:

- Ion mobility measurements;
- HPXe detector: novel geometries for high pressure gas detectors, with the aim of producing an industrial prototype;
- 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).

Stated objectives for past year

Continue the study of the performance of the HPXe detector, now for gamma rays, understanding the parameters that may improve its performance, namely in energy resolution, eventually through the compensation of solid angle effects and the use of digital signal processing.

The possibility of changing the geometry of the HPXe detector to make it more adequate for other applications (e.g., radon detection in consumable water) and eventually more efficient in the light collection will also be evaluated.

The experimental systems to measure positive ion mobility will continue working following the collaboration with the Univ. of Bonn (Germany), namely in the current study of the ion mobility in Ar-CF4-IsoButhane mixture (T2K mixture) for the LCTPC collaboration, and other mixtures considered interesting for large volume detectors. The negative ion mobility system is being assembled at the moment and will allow the continuity of the collaboration started with JINR for the coming years.

The measurement of electroluminescence yield and charge gain of noble gas mixtures doped with electronegative gases, like SF6, 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 recent attention in the scientific community. The experimental systems to do such measurements are accessible, and this work is only depending on the availability of manpower.

Also, experimental systems to measure electron diffusion and drift velocity are being projected and will soon be implemented by PhD student Alexandre Trindade, allowing to obtain these parameters for any needed mixture. The tests will start with noble gases and their mixtures, to cross-check the results obtained by Monte Carlo simulation in the scope of the XIPE collaboration, and the possibility of combining noble gases with quenching additives like DME and isobutane.

Achievements and responsibilities during the past year

The development of a ruggedized high pressure Xe filled detector, optimized for field applications, namely for homeland security applications and geological boreholes prospection has been concluded. The prototype was conceived within the team: the MultiGrid High Pressure Gas Proportional Scintillation Counter (MGHP-GPSC). The detector features a photocathode deposit integrated in the gas volume, which avoids the need for optical windows and microstructures or photodiodes. As a consequence it is more ruggedized than the standard GPSCs. Additionally, it provides improved energy resolution, as the gain of this device is scintillation mediated, not involving any charge multiplication.The detector has been tested for its performance with alpha particles, namely by measuring its gain and achievable energy resolution. The performance dependence on the different adjustable parameters of the detector, like the voltage applied to the anode and collecting grid and gas pressure (up to 3 bar) were also made. Some tests with gamma rays for higher pressures (8-15 bar) were be performed, although limited due to problems with the available high voltage sources. The PhD student responsible for this project has successfully presented his thesis.

The search for the ideal additive is still an issue for the NEXT International Collaboration as it is of interest mainly for the more massive versions of the experiment. Up to now we have successfully answered to all the requests atributted to our team by the collaboration so the goals have been attained.

The new experimental device to measure electron drift parameters, namely their drift velocity and diffusion, has been designed and is now under construction in the workshop.

Lines of work and objectives for next year

The development of an experimental chamber to measure both negative and positive ion mobility was already performed as part of a MSc thesis that finished in September 2018. The prototype was tested and some of the problems encountered are now being dealt with, also as part of a project developed by a MSc student. Results with this experimental system are expected during this year.

Our involvement in NEXT is due to the team knowledge in Xe gas detectors based on electroluminescence, both in experimental and simulation studies and is mainly related with understanding unexpected issues of the detector behavior in the operation stages. At the moment the NEW-White (10 kg Xe) detector is operating and some issues have come about that need to be understood before going to the next prototype (100 kg).

These issues, if left unsolved, may compromise the next upgrade version, namely concerning energy resolution and tracking capability. Our team will try to answer the problems related to our line of work, namely by simulating the drift of electrons in the track and their recombination with the produced ions, both in pure Xe and in Xe-He (or other additives) mixtures. To complement these simulation studies, our available experimental systems of gas mixtures will also be used.

The HPXe detector is undergoing an upgrade considering its use for gamma-ray detection. This upgrade will require further studies, and possibly the simulation of the detector behavior using the GEANT4 or Penelope packages, since the track of electrons for this radiation will be quite different from that of alpha particles. This simulation may indicate which problems should be addressed first, namely solid angle correction, or different grid biasing and next steps to take to optimize the detector.

The device to measure the drift parameters in gases will hopefully be fully operational in a few months time and we intend to have results as soon as possible since this information is also of great importance to the NEXT Collaboration. The comparison between the obtained experimental results with Monte Carlo predictions, when available, will allow to assess the validity of the measurements and to extend them to mixtures.

Medium-term (3-5 years) prospects

The objective of the Gas detectors group for the upcoming years is to develop novel geometries for gas detectors, with the aim of eventually producing an industrial prototype and answer to the needs in the challeging range of high and low energy detection. Also, we intend to use the knowledge acquired to improve the gas parameters measurements and studies, allowing the broadening of the scope of our studies, namely the study of negative ion mobility (needed for the NITPC's), production diffusion coefficients, transverse and longitudinal, drift velocities of both electrons and ions. This will be made with a special focus on the needs of the NEXT and RD51 collaborations.

Future work for the next 5 years will also depend on issues that will arise in these international collaborations, in the case of NEXT, namely with the assembly and first tests with the 100 kg TPC and also on the available funding and human resources that has been very uncertain in he last years.

SWOT Analysis

Strengths and opportunities

The main challenges will be to transfer this knowledge to more practical applications, namely to industry or homeland security, and also to publicise the results obtained to the scientific community in order to establish collaborations with other groups and funding.

Opportunities come basically from international contacts, awareness and knowledge of our work. There is a serious possibility of expanding our work 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.

Weaknesses and threats

The group has several areas to develop and room to innovate, but the unpredictability and lack of funding are a severe constraint. Although the group keeps pursuing all possible opportunities, lack of funding definitely affects the development of the work in progress, but also its dissemination, which prevents the awareness from the scientific community of our work. Frequently, the reason invoked for not granting financial support is the lack of international acknowledgement of the work, closing a circle from which it is difficult to escape.

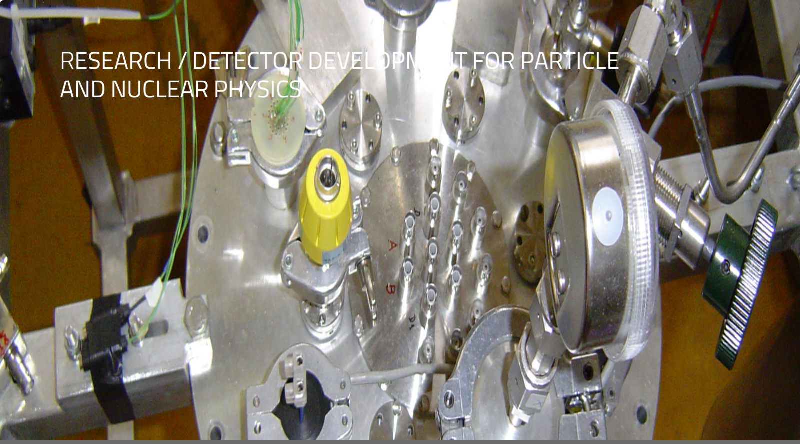
Theses

2 PhD

- André Cortez: ***"Novel Techniques for High Pressure Noble Gas Radiation Detectors"***, 2014-01-01 / 2018-11-28, (finished)
- Alexandre Fonseca Trindade: ***"Study of noble gases mixtures characteristics as a detection medium"***, 2017-01-01 , (ongoing)

1 Master

- Miguel Santos: ***"Development of a Negative Ion Drift Chamber and Study of negative ion transport properties in gaseous mixtures of interest"***, 2017-09-01 , (ongoing)



LIQUID XENON R&D

Principal Investigator:
Vitaly Chepel (50)

3 *Researcher(s):*
Francisco Neves (18), Luís Margato (17), Vladimir Solovov (17)

Total FTE:
1.0

Executive summary

In the year 2018 the work of the group Liquid Xenon R&D Group has been strongly conditioned by the lack of human resources and financial support, as well by the uncertainty concerning the funding of the proposal submitted to the National CERN Fund in mid 2017. Approved in the end of 2018, with a delay of almost one year and a half, the funding has been severely reduced with respect to the original proposal, in spite of the fact that it represented a merge of three proposals from three Portuguese institutions, as it was advised by the Committee. Given the above mentioned uncertainty with funding, no real progress can be reported except for a number of discussions of the group member with the representatives of other groups to set future plans.

Sources of funding

Code	Amount	Dates	Description
CERN/FIS-INS/0025/2017 - LXe	35.000 €	2018-05-01 / 2020-04-30	Participation in RD51 - LXe

Total: 35.000 €

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 (assuming its approval in due time) where experimental studies of density effects on secondary scintillation signal formation in xenon time projection chambers are foreseen. The setup is planned to be designed and possibly manufactured, in part.

Achievements and responsibilities during the past year

The project "Participation in the RD51 Collaboration at CERN" has been recommended for funding in the beginning of 2018, with a very much reduced budget, especially taking into account the involvement of two other institutions besides LIP. The approval came only by the end of the year. Given that uncertainty and also the fact that no other support was available, no advances have been made, except discussions of possible future developments, including those with representatives of the other groups involved in the project.

Lines of work and objectives for next 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.

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. Uncertain in the scope of 5 years.

SWOT Analysis

Strenghts

Highly qualified team with many years of experience in the field.

Weaknesses

Heavy involvement of the team members in other activities and projects. Systematic underfunding, degradation of the experimental base.

Opportunities

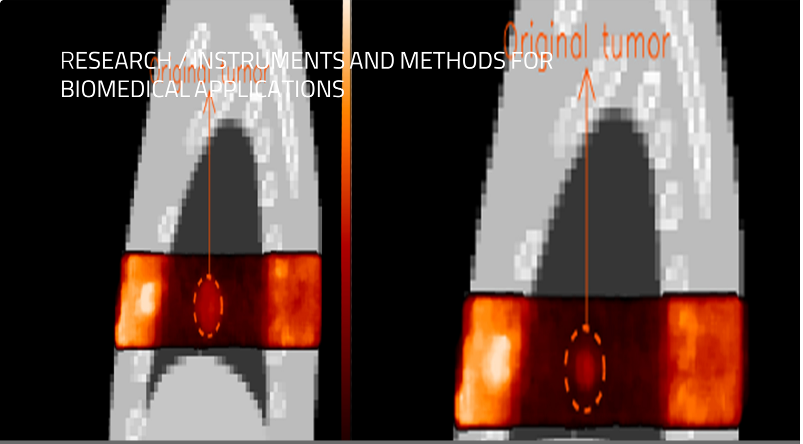
There is a good opportunity of understanding some fundamental aspects of the detector physics and provide a valuable input for future large scale detector development.

Threats

Lack of support for R&D projects. Lack of long and medium term scientific policy.

[Instruments and methods for biomedical applications]

OR Imaging
Gamma Cameras
Dosimetry



OR IMAGING

Orthogonal Ray Imaging for Radiotherapy Improvement

Principal Investigator:
Paulo Crespo (65)

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

Total FTE:
1.7

(*) starting in 2019

Article(s) in international journals:
2 Direct contribution
International conference(s):
2 Oral presentation(s)
1 Proceeding(s)
International meeting(s):
1 Oral presentation(s)
National conference(s):
4 Oral presentation(s)
Seminar(s):
1 Seminar(s)
Completed theses:
1 PhD

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.

In the first case we have managed in the past year to complete data processing regarding the analysis of a cavity irradiated inside an acrylic, cylindrical phantom, with data taken by means of a small-scale OrthoCT system. The results proved for the first time that it is possible to obtain images of the interior of an object without rotating the X-ray source. Part of these results were presented orally at the 2018 IEEE Nucl. Sci. Symp. & Med. Imag. Conference in Sydney, Australia. A more complete description of the whole work is under preparation for submission to a peer-reviewed journal specialized in radiation and imaging in radiotherapeutical environments. The group will be hosting soon an ERASMUS grantee who will study whether changing crystal positioning may yield even better OrthoCT images.

In the second case stated above, a multi-leaf collimator has been fully optimized by Geant4 simulation and self-developed reconstruction routines. The optimization was based on the analysis of images obtained after the irradiation of the NCAT (cardiac-torso anthropomorphic phantom) phantom with realistic, therapeutic proton beams. Three scenarios were considered: (1) an irradiation of the head of the patient with and without nasal cavities fillings; (2) an irradiation of the region of the pituitary gland for three different brain densities (mimicking the possible presence of edema formation); and (3) a pelvic irradiation with patient mispositioning (e.g. patient weight change). The most difficult scenario to discriminate was the irradiation of the pituitary gland. Here, edematous tissue may account for a Bragg peak shift as small as 2 mm only, which the O-PGI system was able to discriminate clearly. These results were published in Physica Medica. However, scintillating crystals and their granularity and positioning were not considered in this first stage. Work is now ongoing in order to devise an optimum crystal glanularity and positioning so that the 2-mm resolving power is maintained with a realistic O-PGI system. Finally, organ motion (e.g. lung) and vertebra motion in TBI (total body irradiation) for pediatric irradiation will also be analyzed via Monte Carlo simulations.

OR Imaging

Lines of work and team organization

The lines of work are mainly divided upon simulation and experimental work. Our colleagues from two hospitals providing high-energy X-ray-based radiotherapy treatments (Coimbra University Hospital Center and the Portuguese Oncology Institute of Porto) (1) have helped in carrying out the experimental work, and (2) gave their expert opinion on what simulations are of foremost importance.

At LIP and University of Coimbra we have so far engaged one assistant professor (project PI), and two postdocs putting forward efforts in simulations regarding the development of an O-PGI system for monitoring proton radiotherapy.

On the experimental side, the high-precision, Mechanical Workshop of LIP, together with its Detector Laboratory have finalized the construction of a small-scale OrthoCT system that we have planned in collaboration. As predicted last year, that data taking at a therapeutic linac did already occur, with very encouraging results obtained for irradiation in FFF mode (flattening-filter free). For the irradiation in the presence of a flattening filter (older treatment modalities), both simulation and experimental results have shown that the background arising from the linac compromises the imaging capability of the OR imaging system, making it not possible to visualize the air cavity in the center of the acrylic phantom. An ERASMUS grantee will soon join the team efforts in devising optimum crystal positioning in OrthoCT by means of Monte Carlo simulations.

Stated objectives for past year

Analysis of the results obtained with FFF (flattening-filter free) and FF (with flattening filter) under the irradiation with a therapeutic-like beam at the Coimbra University Hospital Centre (CHUC E.P.E.) is now ongoing. This constituted the most important objective for the past year.

Nevertheless, the so far very motivating results (correlation of the experimental small-scale OR images with the dose and the clear spatial correlation with the embedded air cavity) can be complemented by further simulations that could not be undertaken during the past year, namely:

-Adaptation of the simulation code in Geant4 to the DICOM medical imaging data format, thus (later) enabling the computation of real treatment plans. This includes inputting into Geant4 3D and 4D computed tomograms with patient data containing a tumor positioned in different locations in accordance with the respiratory cycle and/or patient dislocation and/or other physiologic movements such as bowel movements. Beam directions as indicated by the treatment planning should also be provided so that simulations take that variable into account if and when necessary.

- Adaptation of the simulation code in order to include the possibility of simulating the latest fiducial markers (usually gold-made small rods) imparted onto the bladder of a prostatic cancer patient.

Achievements and responsibilities during the past year

In the past year the team managed to complete data processing regarding the analysis of a cavity irradiated inside an acrylic, cylindrical phantom, with data taken by means of a small-scale OrthoCT system developed at LIP. The results proved for the first time that it is possible to obtain images of the interior of an object without rotating the X-ray source. Part of these results were presented orally at the 2018 IEEE Nucl. Sci. Symp. & Med. Imag. Conference in Sydney, Australia. A more complete description of the whole work is under preparation for submission to a peer-reviewed journal specialized in radiation and imaging in radiotherapeutical environments. The group will be hosting soon an ERASMUS grantee who will study whether changing crystal positioning may yield even better OrthoCT images.

Also during the past year, a multi-leaf collimator has been fully optimized by Geant4 simulation and self-developed reconstruction routines. The optimization was based on the analysis of images obtained after the irradiation of the NCAT phantom with realistic, therapeutic proton beams. Three scenarios were considered: (1) an irradiation of the head of the patient with and without nasal cavities fillings; (2) an irradiation of the region of the pituitary gland for three different brain densities (mimicking the possible presence of edema formation); and (3) a pelvic irradiation with patient mispositioning (e.g. patient weight change). The most difficult scenario to discriminate was the irradiation of the pituitary gland. Here, edematous tissue may account for a Bragg peak shift as small as 2 mm only, which the O-PGI system was able to discriminate clearly. These results were published in Physica Medica. However, scintillating crystals and their granularity and positioning were not considered in this first stage. Work is now ongoing in order to devise an optimum crystal glanularity and positioning so that the 2-mm resolving power is maintained with a realistic O-PGI system. Finally, organ motion (e.g. lung) and vertebra motion in TBI (total body irradiation) for pediatric irradiation will also be analyzed via Monte Carlo simulations.

Lines of work and objectives for next year

For the next year two lines of work are 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 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).

If funding is granted, the construction of a small-scale O-PGI system may be started. The goal is building a 4-parallel slabs system in order to test the feasibility of applying the so-called shifting time-of-flight method for imaging proton beam therapy (PTB).

Medium-term (3-5 years) prospects

Prospect 1 – Achieving by Monte Carlo simulation optimum crystal positioning and pixelization for imaging Bragg peak deviations of 2 mm or smaller in an anthropomorphic phantom (NCAT or, if available, the higher spatial resolution XCAT).

Prospect 2 - Construction and in-beam data acquisition with a small O-PGI camera (shifting-TOF included in DAQ). Proton beam time already granted at PTCHolland (TU-Delft, The Netherlands).

Prospect 3 - Simulation in GEANT4 of tumor motion in lung and near-heart irradiation (XCAT anthropomorphic phantom)

Prospect 4 - Adaption to GEANT4 of pediatric anthropomorphic phantom with elongation/contraction of spinal cord and subsequent orthogonal prompt gamma imaging studies

SWOT Analysis

Strengths

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

Weaknesses

The high out-of-field photon flux existing in a clinical linac force OrthoCT to be surrounded by heavy shielding. This weakness can be surpassed by proper robotic solutions to position the whole detector assembly; nevertheless, they come at non-negligible price.

Opportunities

The higher the degree of conformality achievable by means of external beam radiotherapy, the equally higher is the demand for patient imaging just prior (on-board) or during the therapy session, in order to ensure that the high conformal capability of the treatment is reaching its goals (tumor irradiation, sparing of organ(s) at risk or healthy tissue). OrthoCT represents an added value in both scenarios: on-board and/or real-time patient imaging.

Threats

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

OR Imaging

Publications

2 Articles in international journals

(with direct contribution from the team)

- *"Optimization of the signal-to-background ratio in prompt gamma imaging using energy- and shifting time-of-flight discrimination: experiments with a scanning parallel-slit collimator"*, P. Cambraia Lopes, P. Crespo, J. Huizenga, D.R. Schaart, IEEE Trans. Radiat. Plasma Med. Sci., vol. 2, pp. 510-9
- *"Simulation of proton range monitoring in an anthropomorphic phantom using multi-slat collimators and time-of-flight detection of prompt-gamma quanta"*, Patricia Cambraia Lopes, Paulo Crespo, Hugo Simoes, Rui Ferreira Marques, Katia Parodi, Dennis R. Schaart, Phys. Medica 54 (2018) 1-14

1 International Conference Proceedings

- *"Rotation-free scattered-radiation imaging with a radiotherapy X-ray linac"*, H. Simões, R. Ferreira Marques, P.J.B.M. Rachinhas, A. Wagner, P. Crespo, 2018 IEEE Nucl. Sci. Symp. & Med. Imag. Conf. (NSS/MIC), Nov. 10–17, 2018, Sydney, Australia

Presentations

2 Oral presentations in international conferences

- Paulo Crespo: *"In-vivo monitoring in proton radiotherapy with prompt-gamma multi-slat imaging: A realistic Monte Carlo study"*, 2018-06-25, IWORID – 20th Int. Workshop on Radiat. Imag. Det, Sundsvall, Sweden (invited oral presentation)
- Hugo Simões: *"Rotation-free scattered-radiation imaging with a radiotherapy X-ray linac"*, 2018-11-10, 2018 IEEE Nucl. Sci. Symp. & Med. Imag. Conf. (NSS/MIC), Sydney, Australia

1 Oral presentations in international meetings

- Hugo Simões: *"OrthoCT for assisting external-beam radiotherapy: 2D morphological image obtained experimentally without X-ray source rotation"*, 2018-03-12, MediNet Network Meeting, Vinca Institute of Nuclear Sciences, Belgrade, Serbia

4 Presentations in national conferences

Hugo Simões: *"OrthoCT for assisting external-beam radiotherapy: 2D morphological image obtained experimentally without X-ray source rotation"*, 2018-02-16, Jornadas do LIP 2018, Évora, Portugal

Paulo Crespo: *" In-vivo monitoring in particle and photon radiotherapy: Status and R&D trends"*, 2018-03-23, Workshop on Future Directions in Nuclear Sciences Applied to Health, University of Coimbra, Portugal

Paulo Crespo: *" In-vivo monitoring in proton radiotherapy with prompt gamma multi-slat imaging: A realistic Monte Carlo study, Symposium on New Horizons for Nuclear Sciences and Technologies in Portugal: health and cancer applications"*, 2018-04-27, , Center for Nuclear Sciences and Technologies–C2TN, Lisbon (Invited oral presentation)

Paulo Crespo: *"Desafios científicos e tecnológicos da terapia com protões"*, 2018-07-03, Ciência 2018, Centro de Congressos de Lisboa, Portugal

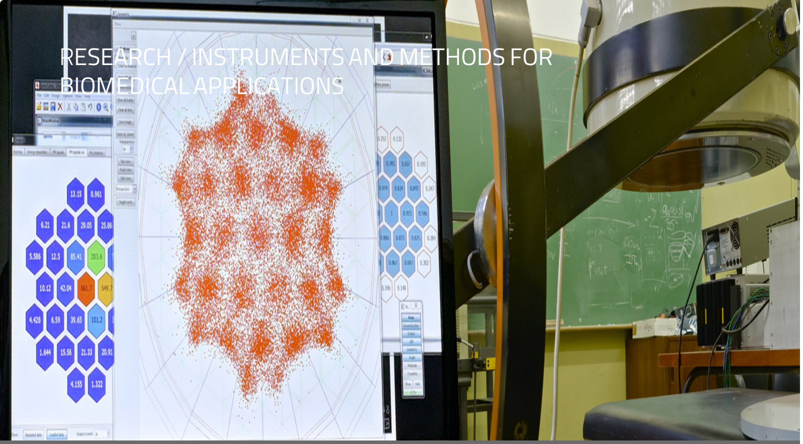
1 Seminars

Paulo Crespo: *"In-vivo monitoring in particle and photon radiotherapy: Some R&D trends"*, 2018-04-19, , Technische Universität Dresden, Germany

Theses

1 PhD

Hugo Simões: *"Demonstração de um dispositivo de imagiologia por raios ortogonais para apoio à radioterapia externa de fotões"*, 2013-09-01 / 2018-07-06, (finished)



GAMMA CAMERAS

Adaptive methods for medical imaging with gamma cameras

Principal Investigator:
Vladimir Solovov (35)

5 *Researcher(s):*
Andrey Morozov (50), Francisco Neves (10), Isabel Lopes (20), Luís Pereira (30), Vitaly Chepel (30)

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

1 *PhD Student(s):*
João Marcos (100)

Total FTE:
2.8

International conference(s):
1 Oral presentation(s)
National conference(s):
2 Oral presentation(s)

Executive summary

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

Sources of funding

Code	Amount	Dates	Description
IF/00378/2013/CP1172/CT001	50.000 €	2014-01-01 / 2018-12-31	Expl. 2014 AM - IF/00378/2013/CP1172/CT001

Total: 50.000 €

Gamma Cameras

Lines of work and team organization

- **Autocalibration and fast calibration algorithms for PSSD**. In this line of research, we look for expanding the range of detector configurations for which the self-calibrating techniques can be applied. Of particular interest is calibration of detectors with sensitivity in all three coordinates. We also look for possibilities to apply our expertise in areas beyond medical imaging, e.g. astrophysics and neutron detection.
- **Development of simulation and data processing/reconstruction software for PSSD**. The open source ANTS2 software package, developed by the group, provides a set of easy-to-use tools for simulation and reconstruction of scintillation events in 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. Currently we are working on promoting ANTS2 for use by other groups: creating better documentation and tutorials as well as integrating it with a third party open source package for SPECT and PET reconstruction.
- **High resolution multi-isotope SPECT and PET**. These are two fields of research for which fast calibration of scintillation crystal response in 3D can be highly beneficial. Our work in this direction is in collaboration with the Radiation Detectors and Applications Group at Politecnico di Milano that develops INSERT - multi-isotope SPECT brain imaging system. We also believe that our calibration techniques applied to small-animal PET can result in the development of a compact low-cost high resolution system. Here we are currently in the phase of a feasibility study with Monte Carlo simulation.
- **Experimental work required for validation of our calibration and reconstruction techniques**. This includes work with a clinical gamma camera upgraded for statistical event reconstruction and the development of high resolution compact PSSD that can be used in devices for prostate and intra-operative imaging. The experiments provide feedback that is essential for development of viable reconstruction algorithms and software.

Stated objectives for past year

The following lines of work were envisaged in the framework of this group for the past year:

- Development of calibration algorithms that would allow practical implementation of 3D position reconstruction in thick scintillation crystals.
- Development of the ANTS2 software and increase of its user base.
- Development a prototype of a hand-held gamma camera for sentinel node surgery and thyroid imaging.
- Commercialization of the concept of self-calibrating clinical gamma camera.

Achievements and responsibilities during the past year

3D calibration of thick scintillation crystals

This work was carried out in collaboration with the Radiation Detectors and Applications Group at Politecnico di Milano. Previously, the Monte Carlo simulation with ANTS2 package demonstrated that position sensitivity can be achieved in an off-the-shelf commercial cylindrical LaBr3:Ce crystal read out from only one side by an array of SiPMs. The method, based on statistical position reconstruction, requires the light response functions of the detector SiPMs to be known. We developed a calibration technique where the detector is scanned by a knife-edge gamma-ray beam in three orthogonal directions, followed by data processing based on modern machine learning methods. The machine learning is employed to clean the datasets from Compton contamination and to reconstruct event positions by cross-correlating datasets from different scans. The prototype implementation of this technique was successfully tested by Monte Carlo simulations. The experimental test is planned for mid-2019 in collaboration with Politecnico di Milano.

Development of the ANTS2 software and effort to increase its user base

New features:

- The upgrade of scripting engine allowed to expose many more of internal data structures and functions to the scripts, providing much more powerful scripting capabilities. Python was added to ANTS2 as second scripting language.
- Neutron tracking code was significantly extended to allow to import neutron scattering data in standard database formats. Additionally, integration of N-Crystal neutron tracking library allowed to add coherent neutron scattering to the list of simulated processes.
- The further development of the Distributed ANTS concept lead to creation of internal master-slave architecture, where several instances of ANTS can be run in a slave mode accepting jobs over network from the master instance. Once configured, this setup is fully transparent to the operator of the master instance, who can run simulation or reconstruction tasks (both interactively and in script mode) using all the threads provided by the slaves attached to the master. Automatic load balancing ensures that the work is distributed according to available computing power, thus minimizing the total computation time.

- To make sure that ANTS can be used on all popular operating systems and to simplify its deployment, we created a Docker version of the package. Now ANTS can be run as a Docker container with GUI accessible through a HTML5-capable browser (i.e. any modern browser). There is also a headless option specifically to use as a slave in the distributed ANTS environment. Containerized ANTS has already been used to run massively parallel simulations at the NERSC supercomputing center by our colleagues from LBNL.

User base:

- The toolkit is broadly used at LIP (by the members of the Gamma Cameras group, the Neutron Detectors group, the Dark Matter group and the Gaseous Detectors group, among others) as well as by the international partners of our lab from Istituto Politecnico di Milano, MEPhI institute of Moscow, LZ dark matter search collaboration, Lawrence Berkeley National Laboratory and the neutron detector development group of the SINE2020 consortium. Position reconstruction module of the main LZ analysis code LZAP is based on ANTS2 code.
- In 2017 we have hosted a student from Istituto Politecnico di Milano (Italy); in 2018 a student from the National Research Nuclear University (Russia) has worked one month in our group. In February 2019 a PhD student from Forschungszentrum Jülich (Germany) will stay with us to gain expertise in using ANTS2, and a stay for a senior researcher from Rutherford Appleton Laboratory (UK) is scheduled in March.

Concept of a hand-held clinical gamma camera

Unfortunately, the project for developing a hand-held gamma imager for assisting the sentinel node biopsy surgery was not funded at the recent FCT/PTDC call. However, João Marcos continued working towards the construction and characterization of the camera prototype as part of his PhD program. During the last year:

- The key components of the detector head, namely the scintillation crystal, SiPM array and collimator were purchased.
- Portable data acquisition system with integrated front-end electronics was assembled and characterized. The system was successfully tested with a neutron Anger camera in the neutron beam at ILL, Grenoble (France).
- Software for processing of the acquired data was developed and tested. The capability of real-time image reconstruction from the acquired data was demonstrated.

Lines of work and objectives for next year

The objectives for the next year are:

- Continue the work on 3D position sensitivity in thick monolithic scintillation crystals. This includes development of reliable calibration technique and experimental validation.
- Integrate GEANT4 as a particle simulation backend into 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:

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 previously proposed the calibration technique via scanning by knife-edge gamma-ray beam in orthogonal directions. Last year we applied this technique to Monte Carlo generated data with promising results. The experimental test for this technique is planned for mid-2019 in collaboration with Politecnico di Milano.

The limitation of the technique described above is that it requires access to strong radioactive sources, not available in many smaller laboratories (including LIP). As alternative, we plan to develop a technique based on electronic collimation using a positron source and a calibrated reference detector (not necessarily 3D).

Integrate Geant4 as a particle simulation back-end into ANTS2 package

The photon tracer of ANTS2 has already a large variety of physical process included, it is fast, convenient to use and, as it focuses on a specific class of detectors, offers many features not available in Geant4. On the other hand, simulation of particle interactions is quite limited in ANTS2, and requests were already made from the users to enhance the simulation capabilities (e.g. to simulate multiple scattering of electrons, include generation of X-rays and perform detailed simulations of neutron interactions).

Instead of implementing these processes in ANTS2, we propose to create an interface between ANTS2 and Geant4 and delegate complex simulations to the latter. The cycle can, for example, be like that: the user configures the detector in ANTS2 GUI benefitting from all the tools developed there; ANTS2 runs the particle simulation using Geant4; and receives back the energy deposition data. Then the data are used to generate optical photons, which are traced in ANTS2 using its own tools.

This approach will increase the available physics processes, allowing to enlarge the application range of ANTS2. For example, at a certain stage the user might be interested in a detailed simulation of the detector background, which has to be delegated to Geant4. Also, at a certain detector development stage, for example after the detector design is already established and optimized in ANTS2, the user might want to perform Geant4 simulations for validation of the results. In this stage an automatic generation of all the necessary Geant4 files is an attractive option.

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 an everyday basis. We proposed to build a prototype of a two-purpose portable gamma camera with sufficient resolution for using in thyroid imaging when not employed in surgery. Our unique know-how in calibration and simulation techniques would allow us to minimize the maintenance costs.

This is an attractive direction as it would allow us to develop a practical device for clinical use in close cooperation with physicians, physicists and technicians from the nuclear imaging department of CHUC. Unfortunately, under the current FCT evaluation guidelines, this project was not considered innovative enough to be funded. Given that considerable manpower and other resources have already been invested in this line of research and most of the expensive components (scintillator crystal, SiPM array, collimators and data acquisition system) are already purchased, we are determined to build and test the prototype in 2019 in collaboration with CHUC. The future strategy in this line will depend on the FCT/European funding policy.

Medium-term (3-5 years) prospects

Geant4 and ANTS2 integration

Problem: While Geant4 has many virtues, user-friendliness is not one of them. ANTS2 is user-friendly and is optimal for rapid prototyping and design work, though its particle tracking capabilities will never match those of Geant4.

What is proposed: develop a simulation environment to use the best of the two approaches. Build an integrated ANTS2-Geant4 environment where the detector model is created in ANTS2 and exported to Geant4 for particle tracing. The resulting energy deposition data then automatically imported back into ANTS2 for optical tracing, analysis, reconstruction etc.

Web interface of ANTS2: didactics and outreach

Problem: Lack of intuitive tools for demonstration of the working principles of particle detectors in a classroom environment and outreach projects.

What is proposed: Build an interactive system with JavaScript front-end running in a web browser and ANTS2 server as the back-end. The students will be able to study working principles of a detector “in action” by running a set of simulations with the possibility of adjustment of key parameters through a web interface with simulation results immediately displayed in the same web page. The default front-end will present a streamlined configuration interface integrated with the 3D visualisation window. It will be also possible (through the ANTS2 scripting) to configure the front-end as different environments: presentation, interactive demonstration, problem solving, quiz, etc. The web interface will be able to run on any device supporting a modern web browser, including tablets and smartphones, permitting the use of the aforementioned environments in outreach activities, such as presentation booth in exhibitions and in hands-on sessions in 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 GPU implementation of it up to date.

What is proposed:

- Use vector processing (SIMD – Single Instruction Multiple Data) capabilities of modern CPUs to improve photon tracing speed in ANTS2 by a factor of 4.
    - Implement photon tracing on Graphics Processing Units (GPU), based on the work of GeantV and VecGeom teams. 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.

Presentations

1 Oral presentations in international conference

- Andrey Morozov: ***"Recent upgrades of the simulation, geometry and reconstruction modules of the ANTS2 toolkit"***, 2018-11-10, 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference, 10-17 November 2018, Sydney, Australia

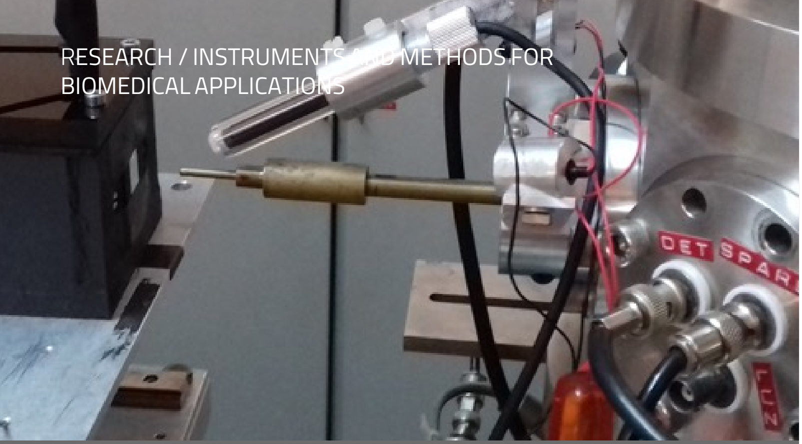
2 Presentations in national conferences

- Vladimir Solovov: ***"Calibration of scintillation cameras: machine learning approach"***, 2018-02-16, Jornadas do LIP 2018, 16-18 Feb 2018, Évora, Portugal
- João Marcos: ***"Collimator design for low energy (140 keV) functional imaging using small field-of-view gamma cameras"***, 2018-07-09, 2018 DAEPHYS School/Workshop on Physical Characterization of Materials, July 9-13, 2018, Universidade de Aveiro, Aveiro, Portugal

Theses

1 PhD

- João Marcos: ***"Real-time statistical event reconstruction for medical scintillation cameras"***, 2015-01-01 , (ongoing)



DOSIMETRY

Principal Investigator:
Luis Peralta (50)

2 *Researcher(s):*
Jorge Sampaio (30), Patrícia Gonçalves (10)

1 *PhD Student(s):*
Pamela Teubig (20)

3 *Master Student(s):*
Ana Campos (10), Duarte Guerreiro (33), José Miguel Venâncio (100)

Total FTE:
2.5

Article(s) in international journals:
8 Direct contribution
1 Indirect contribution
National conference(s):
1 Oral presentation(s)
Event(s):
2 Events organized

Executive summary

Over the last 20 years the interest in the use of protons for radiation therapy treatments has increased. More recently the number of centers and facilities dedicated to proton therapy has increased in Europe. Protons have advantages over photons on what concerns tumor therapy, being particularly helpful for the treatment of deep-seated tumors located close to critical organs.

The possibility of the installation of a proton therapy facility in Lisbon opens a window of opportunity for research in this area. LIP has a long term expertise in photon and electron dosimetry. From accelerator simulation to dosimeter prototyping the work in the field expands over 20 years. This expertise can now be directed to exploit new developments in proton therapy.

The group is divided into two thematic lines: clinical dosimetry, focusing on the use of plastic scintillators and optical fibers in the context of clinical dosimetry for particle therapy; and High-LET radiation microdosimetry, focusing on the development of radiation detectors able to measure energy deposition at sub-mm scales and on studies of radiation effects at the cell level.

Dosimetry

Lines of work and team organization

The group is divided into two thematic lines:

1. Clinical dosimetry

2. High-LET radiation microdosimetry

The first line is focused on the application of plastic scintillators and optical fibers in the context of clinical dosimetry for particle therapy. The responsible for this line is Luís Peralta.

The second line is focused on the development of radiation detectors able to measure energy deposition at sub-mm scales and on studies of radiation effects at cellular level, aiming at determining the biological efficiency and induced damage of high LET (linear energy transfer) radiation. Jorge Sampaio is responsible for this line of research.

Stated objectives for past year

Development and test of fiber dosimeters for clinical applications, in collaboration with the Nu-Rise company from Aveiro.

Design of a microdosimeter allowing for the determination of tracks and energy at the cell scale (which are stochastic in nature). Study of the potential use of technologies based in plastic scintillators, as well as silicon detectors, with high spatial resolution for microdosimetry.

Update of Auger electron spectra database used to study the energy deposited at the DNA scale.

Achievements and responsibilities during the past year

Development and test of fiber dosimeters for clinical applications, in collaboration with the Nu-Rise company from Aveiro.

Design of a microdosimeter allowing for the determination of tracks and energy at the cell scale (which are stochastic in nature). Study of the potential use of technologies based in plastic scintillators, as well as silicon detectors, with high spatial resolution for microdosimetry.

Update of Auger electron spectra database used to study the energy deposited The collaboration with the Nu-Rise company allowed the development of a fiber dosimeter for clinical staff in intervention cardiology. The purpose of this dosimeter is to make real-time dose monitoring of the clinicians performing intervention cardiology under fluoroscopy. The first hospital tests will take place in 2019 in Hospital de Santa Maria, Lisboa.

In the past few years interest grew around the use of optical fibers for dosimetry in proton therapy. While capable of high position resolution (currently down to 125 μm) scintillating fiber signal suffer from quenching for high-LET charged particles. For protons, the phenomenon is more severe near the Bragg-peak and can be studied in low-energy cyclotrons. To make the simulation of the low-energy proton interaction with matter a fast program (pMC) was developed. The program is adaptated from the AlfaMC code already developed and tested by the group. The program was benchmarked against FLUKA and the results compared for low-energy protons (up to 20 MeV) and simple slab geometry. The pMC program proved to be more that 10 times faster than FLUKA, while the results for deposited energy are similar.

In collaboration with the radiophysics group of the University of Santiago de Compostela (USC), we proposed a project to the ATTRACT call (MICROBIODOS). The aim of this project is to produce and demonstrate a small portable radiation detector system, based on silicon 3D diodes, with radiation hard embedded electronics for readout and analysis, capable of determining in real time the relevant dosimetric and micro-dosimetric quantities needed to assess radiation induced biological effects. We also started a master thesis project to explore the feasibility of system based on 2D and 3D arrays of optical fibers for the characterization of the radiation fields with sub-millimeter resolutions. This system could be used in high-resolution measurements of fluences for the characterization of radiation fields in hadrontherapy and radiation protection, as well as in microdosimetry studies.

In the context of another master thesis concerning the problem of Auger emitters for targeted therapy, the calculations of the atomic transition probabilities of the descendants of 125I (125Te) and 111In (111Cd) were completed. We have made inter-comparisons between the two state-of-art atomic structure codes (MCDGME and GRASP2K) and concluded that the results are very consistent with each other, showing significant differences with the reference EADL database values (specially for the very low-energy transitions). The emission spectra of Auger electrons and X-rays were also generated using the MC based code BrIccEmis. These spectra were input in simulations made with the PENELOPE code in a simple cell model. These simulation show that this updated data may only have significant impact at the nm (DNA) level when compared with simulations using the old reference dataset from the EADL. However, the PENELOPE code does not allow this conclusion to be assessed with complete confidence, since it only allows tracking of electrons with energy greater than 50 eV.t the DNA scale.

Lines of work and objectives for next year

Optical scintillating fibers exist with very small diameter, down to 125 μm. The small dimensions make them interesting for microdosimetry studies. Under proton micro-beam irradiation the deposited energy corresponds to the one deposited on a stack of a few cells. Our plan is to 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 closed. This allows the measurement of direct response to protons, without the contamination from secondary particles, other than electrons. Depending on the achieved results further tests are foreseen for the 18 MeV proton beam at ICNAS/Coimbra cyclotron.

Based on these studies we intend to design a 2D system with optical fibers coupled to a fast readout system (for example, using SiPM). This project will use the information obtained in studies already started to characterize the optical fibers in terms of light yields response (Birk´s law) and quenching effects for protons in the Bragg peak energy region. Cross-talk effects tests between juxtaposed fibers are planned using the fibrometer developed at LIP's LOMaC. It is also intended to use the proton beams available at CTN and at ICNAS to study these effects.

We plan to continue to update the atomic database of the elements considered most promising for Auger electron targeted therapy that were identified by the IAEA. To evaluate the impact of this new database, we intend to implement the simulations using the Geant4-DNA package that allows tracking of particles to very low energies (~eV). We also expect to consolidate the collaboration with the CTN radiobiology group that has developed experimental activities in this topic.

Medium-term (3-5 years) prospects

Protons have advantages over photons on what concerns therapy of deep-seated tumors located close to critical organs. The negligible dose after the Bragg peak is of paramount importance in sparing normal tissues. To treat the tumor's volume, the delivered dose needs to be spread out laterally and along the beam direction producing the Spread-Out Bragg Peak. The uncertainty on the dose curve fallout implies the use of wider tolerance margins and the unwanted irradiation of healthy tissues. The reduction on proton range uncertainty is still an open issue, and one of the most important ones to improve proton therapy.

Radiation-tissue interactions happen at sub-cellular scale and therefore dosimetric quantities at micrometer and nanometre scales should ideally be measured in therapy and radiation protection routine practice. It is thus important to assess and quantify those damages at the sub-cellular level and relate them to physical dosimetric quantities (such as dose or LET) in order to establish a cause-effect relation. For these purposes the RBE is defined. Its value varies with many factors, such as LET, cell type and biological endpoint. For RBE studies there is a growing interested in micro-beam irradiation due to the great advantages in localized energy deposition. The conjugation of micro-beam cell irradiation technics and the use of micron-size dosimeters will open a new fields of research in microdosimetry.

Contacts were established with the group at University of Santiago de Compostela (Spain) to build a collaboration platform for the development of radiation detection systems relevant to proton therapy. This platform may include systems that are being developed in the Dosimetry group as well as other detection systems belonging to biomedical applications research groups at LIP. An application for funding this platform under the Interreg-Sudoe (Research and Innovation) calls is planned for 2019. We would also would like to extend our work in the field of Auger emitters to a new fast growing area of research in proton external therapy combined with targeted therapy with nanoparticles.

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 CTN). 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, almost all PhD researchers are in precarious contracts some of which are likely to be ending in the near future. Difficulty to maintain or attract new students currently finishing the master degree due to the lack of funding for PhD grants.

Opportunities: The installation of a 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. 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 potentiate 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

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

- *"Plastic scintillation detectors for dose monitoring in digital breast tomosynthesis"*, J. Antunes, J. Machado, L. Peralta, N. Matela, Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 877 (2018) 346-348
- *"Temperature dependence of plastic scintillators"*, Luis Peralta, Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 883 (2018) 20-23
- *"Theoretical and experimental determination of K - And L -shell x-ray relaxation parameters in Ni"*, Guerra, M., Sampaio, J.M., Parente, F., Indelicato, P., Hönicke, P., Müller, M., Beckhoff, B., Marques, J.P., Santos, J.P., Physical Review A, 97 (4), art. no. 042501
- *"ALPHACAL: A new user-friendly tool for the calibration of alpha-particle sources"*, A. Fernández Timón, M. Jurado Vargas, P. Álvarez Gallardo, J. Sánchez-Oro, L. Peralta, Applied Radiation and Isotopes 135 (2018) 78–82
- *"Structure of high-resolution Kβ1,3 x-ray emission spectra for the elements from Ca to Ge"*, Ito, Y., Tochio, T., Yamashita, M., Fukushima, S., Vlaicu, A.M., Syrocki, Å.Ł., Słabkowska, K., Weder, E., Polasik, M., Sawicka, K., Indelicato, P., Marques, J.P., Sampaio, J.M., Guerra, M., Santos, J.P., Parente, F. , hysical Review A, 97 (5), art. no. 052505
- *"A combined experimental and theoretical approach to determine X-ray atomic fundamental quantities of tin"*, Y. Ménesguen M.-C. Lépy J. M. Sampaio J. P. Marques F. Parente M. Guerra P. Indelicato J. P. Santos P. Hönicke B. Beckhoff, X-Ray Spectrometry, 47 (5), pp. 341-351.
- *"Experimental and theoretical determination of the L-fluorescence yields of bismuth"*, Ménesguen, Y., Lépy, M.-C., Sampaio, J.M., Marques, J.P., Parente, F., Guerra, M., Indelicato, P., Santos, J.P., Metrologia, 55 (5), pp. 621-630.
- *"Suitability of X ray spectrometry to distinguish a handwritten 16th century real estate sales document from its copy"*, Pessanha, S., Manso, M., Costa, M., Ferreira, A., Silva, R.J.C., Sampaio, J.M., Carvalho, M.L., Spectrochimica Acta Part B Atomic Spectroscopy 146 pp. 21-27

Presentations

1 Presentations in national conferences

- Luis Peralta: *"Who and Where are the Portuguese Experts"*, 2018-11-06, Workshop on Implementation of Proton Therapy in Portugal, Campus Tecnológico e Nuclear, Sacavém, Instituto Superior Técnico

Organized Events

2 Workshops

- *"4º Workshop IDPASC Hands-on Particles and Light"*, [WS] 2018-07-09 / 2018-07-11, LIP, Lisboa
- *"Workshop on Implementation of Proton Therapy in Portugal"*, [WS] 2018-11-05 / 2018-11-06, Campus Tecnológico e Nuclear, Instituto Superior Técnico

Theses

3 Master

- José Miguel Venâncio: *"Study of fiber dosimetry in interventional cardiology"*, 2018-03-01 , (ongoing)
- Duarte Guerreiro: *"Estudo da resposta dosimétrica de cintiladores plásticos em feixes de protões"*, 2018-10-01 , (ongoing)
- Ana Campos: *"Estudo da dispersão de partículas alfa em filmes finos"*, 2018-07-01 , (ongoing)

[Radiation environment studies and applications for space missions]

Space Rad
i-Astro

SPACE RAD

Space Radiation Environment and Effects

Principal Investigator:
Patrícia Gonçalves (70)

5 *Researcher(s):*
Alessandro de Angelis (5), Bernardo Tomé (10), Jorge Sampaio (70), Luisa Arruda (80), Pedro Assis (10)

2 *PhD Student(s):*
Ana Luisa Casimiro (100), Marco Alves Pinto (90)

1 *Master Student(s):*
Filipe Maximo (100)

7 *Trainee(s):*
Beatriz Ferreira, Francisco Carrola, Jorge Marques, João Ricardo Ramalho Silva, Pedro Freixo, Pedro Moreira, Plamen Avramov

2 *External collaborator(s):*
Carlos Garrido, Elsa Susana Fonseca

Total FTE:
5.4

Article(s) in international journals:
4 Direct contribution
International conference(s):
2 Oral presentation(s)
2 Poster(s)
2 Proceeding(s)
National conference(s):
6 Oral presentation(s)
5 Poster(s)
Seminar(s):
2 Seminar(s)
7 Outreach seminar(s)

Executive summary

In the past 15 years, an area of research and development focused on the study of the radiation environment in space and 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, model radiation environments 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 tools, 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 hardeness assurance and effects on biological systems/manned flights.

In its activities, mostly developed under contracts with ESA, LIP has worked with different entities, both from academia and industry.

Sources of funding

Code	Amount	Dates	Description
ESA: 1-7560/13/NL/HB	300.000 €	2014-02-18 / 2020-06-30	RADEM proto-flight model
ESA: 3-14025/13/NL/AK	60.000 €	2014-03-17 / 2018-12-31	MFS Data Analysis
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: 440.116 €

Space Rad

Lines of work and team organization

The key issues for the SpaceRad Group activities are the following:

1. Study of the interplanetary radiation environment, in orbit 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 technologies and dedicated sensors.
2. Assess the effects of radiation on electronics 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 habitats for radiation protection of astronauts and radiation systems in space.
4. The effect of ionizing radiation on cell structure is one of the main factors limiting the survival of life forms in potential astrobiological habitats. The modeling 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, can seriously affect modern technological infrastructure (power distribution networks, telecommunications), especially given the dependence of this infrastructure on applications located in orbit (satellites). The knowledge and study of space weather, and especially the enhancement of the predictive capability of extreme events is fundamental to protect the terrestrial infrastructure, along with the development of mitigation strategies of this type of occurrence.

The current group activities are the following:

RADEM - development of the RADiation hard Electron Monitor for the JUICE ESA mission to the Jovian system, with launch foreseen in 2022. RADEM is developed by a consortium of institutes and industry including LIP and the Paul Scherrer Institute in Switzerland, EFACEC SA in Portugal and IDEAS in Norway.

AlphaSAT radiation Environment and Effects Facility (AEEF) - AlphaSAT is the largest ESA telecom satellite, in 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 geostationary orbit (GEO) radiation environment. LIP was also involved in the ground testing and preparation of the CTTB data analysis prior to the AlphaSat launch.

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 tasks and supervise PhD and master students working in that subject. Luisa Arruda is in charge of the MFS data analysis and co-supervises a master thesis related with the MFS data analysis. Jorge Sampaio co-supervises the work of Ana Luisa Casimiro, in particular in what concerns the effects of radiation on crews and dosimetry and responsible for the CTTB data analysis. Pedro Assis supports the team in the activities requiring the collaboration with the e-CRLab. Patrícia Gonçalves coordinates the Group, supervises the work of Marco Pinto and co-supervises the remaining theses.

Stated objectives for past year

In 2018 the group organized itself around its contractual responsibilities. For the MFS data analysis contracts these consisted on the consolidation of the particle spectra reconstruction methodologies using the MFS, and the publication of the MFS SEP reconstructed data, in particular for electron channels. The analysis of the CTTB data was continued and a dedicated simulation of the test bed was planned to implemented with the objective of better understanding the in-flight response of the EEE components. On the follow up of the RADEM contract, the analysis of the Directional Detector performance, the data analysis of the RADEM calibration campaigns and the coordination of the RADEM ASIC TID test campaigns were to take place in 2018. Additonally the group continued participating in the JUICE Science Working Team and pursuing a flight opportunity for in-flight testing prior to integration in the JUICE mission.

In 2018 the Group expected the outcome of the evaluation of "MarsSEP - SEP propagation model and radiological risk of human exploration of Mars", a proposal to the FCT call for projects in all scientific domains, in which work developed by the group in the area of Mars Radiation Environment description, expertise in the area of data analysis from space instruments and the challenge of describing SEPs near Earth and Mars was put together. Unfortunatelty this proposal was not funded, despite its recognized good scientific quality, due to an average classification in what concerned the PT2020 regional prioritary specialization criteria for the Lisbon Region. The final result of the project evaluation, after appeal due on the 8th of August 2018, was finally received on the 1st of February 2019.

Achievements and responsibilities during the past year

Contractual responsibilties 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.

The analysis of MFS electron data during the SEP event of January 2014, submitted to the conference RADECS 2017, was published in IEEE Transactions in Nuclear Science in 2018.

The Radiation analysis of the RADEM was presented at the NSREC 2018 conference poster session. The RADEM Directional Detector studies and tests were presented in the RADECS 2018 conference poster session, with the title "Development of a Directionality Detector for RADEM, the Radiation Hard Electron Monitor aboard the JUICE Mission" and accepted for publication in IEEE Transactions in Nuclear Science journal.

The group relies on a very strong expertise in Geant4, both from the application developer and toolkit developer point of view. As such, during 2017 and 2018 a tool and user interface enabling to directly export CAD STEP format geometries, with corresponding materials, into a GDML format, which can be directly read by Geant4, was developed. This tool, GUIMesh, 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, and it will surely be a very valuable asset for the future work of the Group. The description of the tool performance and use was acepted and reviewed to be published in Computer Physics Communications.

Training

During 2018 there were two ongoing PhD theses and one master thesis, whose status is described below.

From February to July 2018 ten undergraduated students worked with the SpaceRad Group, in an 3 hour/week internship assignment in the framework of the Course "Nuclear and Particle Physics Technologies" of the 4th year of the Integrated Masters Degree in Physics Engineering of Instituto superior Técnico, for which Patrícia Gonçalves is responsible. These students started the development of a "Virtual Radiation Physics Laboratory" based on Geant4, whose Graphic User Interface enables a fast and userfriendly use. This application simulates gamma ray spectroscopy, Geiger-Mueller counter and positron emission tomography setups. The goal is to provide teachers and undergraduate students with a tool that can be used for demonstration and study purposes.

From July to September 2018, several trainees were supervised by the SpaceRad Group, participating in LIP´s Summer Internship Programme. Their work programme was centered in the development of a prototype of a radiation monitoring system based on COTS to be flown in CubeSats.

Lines of work and objectives for next year

The critical issues for next years are the participation in the instrument development and science teams for planetary missions (to Mars, Jupiter or the Moon) extending the duration of the projects in which LIP is involved; 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 this context for the two years period from the beginning of 2019 to the end of 2020 the Group will continue the activities in which it is involved:

- **The RADEM** contract is ongoing and the tests and calibration of its Flight Model will take place in the beginning of 2020. For this contract there will be need of additional human resources, since Marco Pinto, the PhD student who has been working on the project will finish his thesis during 2019. The additional manpower needed is covered by the contract budget. The group will continue to follow the work and to participate in the Juice mission Science Working Group.
- **The MFS and CTTB Data Analysis** contracts are expected to be continued via a Contract Change Notice already issued to ESA for 2019, and with their integration in the contract for operations of the AlphaSat Environment and Effects Facility for the period 2020-2022. The annual budget corresponding extension to these requests is close to 30 k€, enough to guarantee a Post-doctoral contract to fulfil LIP´s contractual commitments.
- The activities concerning the exploration of the **Geant4** based **Mars Radiation Environment Model** will continue, with the work developed in the PhD Thesis of Ana Luisa Casimiro, aiming at predicting the effect of the energetic particle radiation in manned missions to Mars. This line of work is also bridging with the activities of the Dosimetry group. This thesis is half-funded by a Lisbon University grant.

The group is currently 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 aim of the call is to improve the scientific understanding of the origin and evolution of space weather phenomena, to develop new models and forecasting techniques capable of extending the time horizon of a future space weather forecasting capability to several days, and to inventory potential early indicators of extreme space weather events. The SpaceRad group participation will be to characterise the particle radiation environment on the Moon by developing a model for the lunar radiation environment, using concepts inherited from the detailed Mars radiation environment model (dMEREM), which can be used in the study and forecast of the effects of solar energetic particle events on the moon.

- **Collaboration with the Dosimetry Group**: the LIP Dosimetry Group is 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 space flight, for the study of the effects of high LET ions in the crews.
- **Collaboration with the Gamma Ray Astrophysics in Space Group:** The mission proposal e-Astrogam was not chosen in 2018 as the ESA M5- mission. However, during 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, is being prepared, whose PI is Alessandro de Angelis. This proposal already passed the first stage of approval for the ESA Fast Missions call, is now in phase 2 of the selection, and will be evaluated in June 2019, along with other five mission proposals. The LIP i-Astro Group is involved in the proposal and the SpaceRad group will be involved in the work related to radiation testing and radiation damage to the detector.

The group has also the objective of getting involved in collaborations, projects or contacts related to:

- Astrobiology studies using the Geant4 based Mars radiation environment model;
- Radiation damage in EEE components and dedicated radiation testing at National and European facilities

Theses

- Marco Pinto should finish his PhD thesis on RADEM during 2019
- Ana Luisa Casimiro should have the CAT presentation of her PhD thesis during 2019
- Filipe Máximo should finish his master thesis in the 1st semester of 2019
- Two students enrolled in the master programme in the 2nd semestre os 2018 and will be starting their theses work in February 2019:
    - Luís Sintra, "Particle Energy Spectra Reconstruction of the Multi-Functional Spectrometer In-flight Data using Machine Learning Techniques"
    - Pedro Moreira, "Development of an in-flight EEE component test system with integrated radiation monitoring for TID measurement"

The detailed list of theses ongoing in 2018 is presented at the end of this report.

Medium-term (3-5 years) prospects

For the period 2021 to 2023 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.
- The **MFS and CTTB Data Analysis** contracts are expected to be extended until the end of 2022.
- The continuation of the radiation environment modelling of solar system radiation environments, such Mars and the Moon, and the application of the developed models to future robotic and manned missions.
- Follow up of the collaborations with the Dosimetry and i-Astro LIP groups.

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.
- It is an applied area, not a fundamental science activity, and it can be seen as an interface area to several fields. This can be an advantage for the collaboration with industry 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.

Opportunities

- Collaboration with industry, Contracts with European Space Agency.
- Participation in consortia (LIP is member of the EUROPLANET consortium) for H2020 calls.
- Participation in scientific consortia or teams for future space missions can enhance the scientific component of the activity.

Weaknesses

- The group heavily depends on contracts with the European Space Agency which a typical duration between 1 year to 3 years.
- 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.
- This activity at LIP is not very well known to Physics university students: more outreach and dissemination is needed.

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.
- 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 scientific components can be exploited.

Space Rad

Publications

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

- *"Assessment of radiation exposure in manned missions to Mars for three mission profiles"*, A. L. Casimiro, J. M. Sampaio, P. Gonçalves, M. Pinto, Radiation and Applications Journal (RAD Journal), Volume 3, Issue 1, pp. 27-33, March 2018
- *"Electrons in GEO measured with the ESA Multi-Functional Spectrometer during the January 2014 SEP"*, L. Arruda, P. Goncalves, A. Marques, J. Costa-Pinto, A. Aguilar, P. Marinho, T. Sousa, H. Evans, P. Nieminen, IEEE TNS Vol65, Issue 8 pp 1540 - 1545 August 18
- *"GUIMesh: a tool to import STEP geometries into Geant4 via GDML"*, M. Pinto, P. Gonçalves, accepted for publication on Computer Physics Communications, 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, Accepted for publication on IEEE Transactions on Nuclear Science on 04 Oct 2018, 10.1109/TNS.2019.2900398

2 International Conference Proceedings

- *"Radiation Analysis and Shielding Optimization of RADEM, a Radiation Hard Electron Monitor for the JUICE Mission"*, Marco Alves Pinto, Proccedings NSREC 2018, Hawaii, USA
- *"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, Proccedings RADEC 2018, Gotemburgo, Suécia

Presentations

2 Oral presentations in international conferences

- Jorge Sampaio: *"Space Radiation Environment and Effects at LIP"*, 2018-04-27, MAT Science Week , GSI, Darmstadt, Alemanha
- Ana Luisa Casimiro : *"VALIDATION OF SPACE RADIATION ENVIRONMENT WITH RAD DATA For Dose Assessment in Manned Missions to Mars"*, 2018-10-17, 2nd Mars Space Radiation Modeling Workshop, Southwest Research Institute, Boulder, Colorado

2 Poster presentations in international conferences

- Marco Alves Pinto: *"Radiation Analysis and Shielding Optimization of RADEM, a Radiation Hard Electron Monitor for the JUICE Mission"*, 2018-07-18, NSREC 2018, Hawaii, USA
- Marco Alves Pinto: *"Development of a Directionality Detector for RADEM, the Radiation Hard Electron Monitor aboard the JUICE Mission"*, 2018-09-18, RADECS 2018, Gotemburgo, Suécia

6 Presentations in national conferences

- Patrícia Gonçalves: *" Space Radiation Environment & Effects at LIP"*, 2018-02-18, Jornadas do LIP 2018, Évora
- Marco Alves Pinto: *"Actividades do grupo SpaceRad"*, 2018-02-27, Inside Views, LIP-Lisboa
- Marco Alves Pinto: *"Development of a Directionality Detector and RADEM Radiation Analysis for the JUICE mission"*, 2018-03-24, LIP PhD Students Workshop, Coimbra
- Marco Alves Pinto: *"Das profundezas da Terra ao Espaço"*, 2018-05-09, Outreach session, LIP's anniversary, LIP, Lisboa
- Plamen Avramov: *"O Gant4 aplicado ao ensino da física nuclear e de partículas"*, 2018-08-30, Física 2018 (SPF), Universidade da Beira Interior, Covilhâ, Portugal
- Luisa Arruda: *"Electrons and Protons in GEO measured with the ESA Multi-Functional Spectrometer during the January 2014 and September 2017 SEPs "*, 2018-09-11, XVIII ENAA, Observatório Geofísico e Astronómico da Universidade de Coimbra

5 Poster presentations in national conferences

- : *"Development of a Directionality Detector and RADEM Radiation Analysis for the JUICE Mission "*, 2018-02-17, Jornadas do LIP 2018, Évora, Portugal
- Filipe Maximo: *"SEP fluxes in GEO measured with ESA's Multi-Functional Spectrometer"*, 2018-02-17, Jornadas do LIP 2018, Évora, Portugal
- : *"Assessment of Radiation Exposure in Manned Missions to Mars for Three Profiles "*, 2018-02-17, Jornadas do LIP 2018, Évora, Portugal
- Ana Luisa Casimiro : *"Assessment of Radiation Exposure in Manned Missions to Mars for Three Profiles"*, 2018-03-21, PhD Open Days IST, IST, Lisboa
- Marco Alves Pinto: *"Development of a Directionality Detector and RADEM Radiation Analysis for the JUICE mission"*, 2018-03-21, PhD Open Days IST, IST, Lisboa

2 Seminars

- Patrícia Gonçalves: *"Particle Physics Technologies applied to Space and Biomedical Applications"*, 2018-02-07, Third Lisbon mini-school on Particle and Astroparticle Physics, Oeiras
- Jorge Sampaio: *"Space Radiation Effects on Humans and Machines"*, 2018-11-19, , FCUL

7 Outreach seminars

- Marco Alves Pinto: *"Para o espaço e mais além"*, 2018-10-23, O Espaço vai à Escola, Escola Sec. Eça de Queirós, Lisboa
- Marco Alves Pinto: *"Para o espaço e mais além"*, 2018-10-23, O Espaço vai à Escola, Escola Básica 2, 3 Manuel da Maia, Lisboa
- Marco Alves Pinto: *"Para o espaço e mais além"*, 2018-10-25, O Espaço vai à Escola, Externato Marcelino Champagnat, Lisboa
- Jorge Sampaio: *"Da Terra ao Espaço - o desafio radiológico"*, 2018-11-02, ESERO - O espaço Vai à escola, Escola Secundária Dr. Francisco Fernandes Lopes, Olhão
- Jorge Sampaio: *"Da Terra ao Espaço - o desafio radiológico"*, 2018-11-05, ESERO - O espaço Vai à escola, Escola Secundária António Carvalho Figueiredo, Loures
- Jorge Sampaio: *"Da Terra ao Espaço - o desafio radiológico"*, 2018-11-06, ESERO - O espaço Vai à escola, Escola Secundária D. Filipa de Lencastre, Lisboa
- Jorge Sampaio: *"Da Terra ao Espaço - o desafio radiológico"*, 2018-11-07, ESERO - O espaço Vai à escola, Escola Secundária José Gomes Ferreira, Lisboa

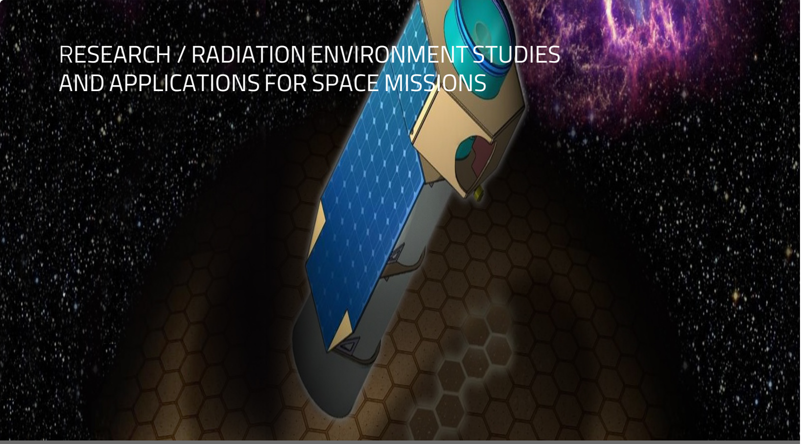
Theses

2 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 , (ongoing)
- Ana Luisa Casimiro : ***"Radiation Hazard Assessment and Mitigation in Manned Missions in the Solar System"***, 2017-02-01 , (ongoing)

1 Master

- Filipe Maximo: ***"Analysis of in-flight data on the AlphaSat radiation Environment Effects Facility"***, 2016-09-01 , (ongoing)



i-ASTRO

Space Instrumentation for Astrophysics

Principal Investigator:
Rui Curado Silva (85)

5 *Researcher(s):*
Alessandro de Angelis (5), Filomena Santos (10), Jorge Maia (45), José Escada (20), Teresa Dias (10)

1 *Technician(s):*
Carlos Patacas (20)

4 *PhD Student(s):*
Alexandre Fonseca Trindade (30), André Cortez (23), Marco Alves Pinto (10), Miguel Moita (100)

1 *Master Student(s):*
Marcela Páscoa (100)

Total FTE:
4.6

Article(s) in international journals:
4 Direct contribution
1 Indirect contribution
International conference(s):
2 Poster(s)
1 Proceeding(s)
National conference(s):
1 Oral presentation(s)
1 Poster(s)
Collaboration meeting(s):
3 Oral presentation(s)
Seminar(s):
5 Outreach seminar(s)
Completed theses:
1 Master

Executive summary

The Space Instrumentation for Astrophysics Group develops its research activities in the framework of mission proposals to ESA and NASA in the X- and gamma-ray domains. The group is part of H2020 AHEAD (Activities in the High Energy Astrophysics Domain) project as well as of All-Sky-ASTROGAM, 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 has a great potential to open a new scientific observational window.

In 2018, in the framework of AHEAD WP9 (Work Package 9), entitled "Assessment of gamma-ray experiments", the e-ASTROGAM and AMEGO instrument mass models were simulated and their polarimetric performances were calculated and analyzed. Polarimetric measurements with a double layer CdTe prototype under a polarized beam were performed at the ESRF (European Synchrotron Radiation Facility) and at LARIX (LARge Italian X-ray facility) facility at the University of Ferrara.

We kept contributing to the development of the main instrument of IXPE mission, by simulating the potential polarimetric performances of different noble gases: Xe, Ar, Ne and He. Research activities in the framework of 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.

Sources of funding

Code	Amount	Dates	Description
654215 - AHEAD	61.225 €	2015-09-02 / 2019-02-28	Integrated Activities for the High Energy Astrophysics Domain

Total: 61.225 €

i-Astro

Lines of work and team organization

The group is focused on the development of focal plane instruments for high-energy astrophysics based in semiconductor, scintillators and gas filled detectors. These instruments are spectro-imagers with polarimetric capabilities. Indeed, polarimetry has been the focus of our instrument development for more than a decade. Our expertise in this field was crucial for our participation in several mission proposals submitted to ESA. These research activities are divided in three lines of work: 1) AHEAD; 2) ProtonRadCdTe project; 3) IXPE mission.

1- The main task of our group in AHEAD WP9 is to contribute to the All-Sky-ASTROGAM and AMEGO missions' mass model simulations. The All-Sky-ASTROGAM proposal was pre-selected for phase 2 of ESA F call. Rui Curado da Silva coordinates the group participation in AHEAD.

1.1- e-ASTROGAM mass model simulations is performed by André Cortez (AHEAD fellowship), under the supervision of Rui Curado da Silva and Filomena Santos.

1.2- Focal plane detector development and polarimetric analysis tasks are part of Miguel Moita PhD thesis, with the support of Marco Pinto, and under the supervision of Jorge Maia and Curado da Silva.

2- The ProtonRadCdTe is a project with the goal of evaluating the proton radiation hardness in CdTe detectors in context of a Low-Earth Orbit (LEO) mission, under the coordination Jorge Maia.

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 Alexandre Trindade's PhD thesis, with the support of José Escada and the supervision of Rui Curado da Silva and Jorge Maia.

3.1- GPD gas mixture simulation is performed by José Escada, under the supervision of Jorge Maia and Rui Curado da Silva.

3.2- GPD gas mixture testing will be performed by Alexandre Trindade under the supervision of Filomena Santos and Jorge Maia.

Stated objectives for past year

The objectives for the past year divided by: 1) AHEAD/e-ASTROGAM; 2) XIPE mission; and 3) BioMeXRay activities:

1- Contribute to the AHEAD WP9 focal plane mass model simulation activities in order to determine the best instrument configuration for the future gamma-ray telescopes.

1.1- Simulating the e-ASTROGAM mission, for different configurations and detector materials with the MEGAlib toolkit;

1.2 – Advisory and consulting tasks on ASTENA (Advanced Surveyor of Transient Events and Nuclear Astrophysics) polarimetry science;

1.3 – Analysis of INTEGRAL IBIS polarimetric data of several strong gamma-ray emitters;

1.4 – Double layer CdTe polarimeter prototype testing through a wider beam energy band (150 keV up to 300 keV) and through finer step range of distances between layers, in order to improve 3D emulation.

2- Optimize XIPE mission GPD gas mixture. Development of an experimental system to measure electron cloud diffusion.

3- Conclusion of BioMeXRay project development. Start the study of the 2D spatial distribution of the low-Z elements (matrix + trace) in the brain tissue samples.

Achievements and responsibilities during the past year

- All-Sky-ASTROGAM proposal was pre-selected for phase 2 of ESA F call.
- In the framework of AHEAD WP9, e-ASTROGAM and AMEGO instrument mass models were simulated and their polarimetric performances were compared. Two communications were prepared for IEEE Nuclear Science Symposium 2018, Sidney, and the INTEGRAL Workshop 2019, Geneva.
- Double layer CdTe detector prototype was tested under a polarized beam at the LARIX beam and at the ESRF under a competitive call. The polarimetric performance results obtained confirmed the potential of multilayer focal plane design for Laue lens and 3D position sensitive detectors;
- Stratospheric Spectropolarimeter Gamma-X experiment selected in a competitive NASA HASP (High Altitude Student Platform) call. CdTe polarimeter prototype for double-event background measurement launched the September 4th at Fort Sumner, New Mexico, USA.
- In BioMeXRay/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 submitted to an international journal.
- The polarimetric performances of several noble gases (Xe, Ar, Ne and He), alone and combined mixtures, were simulated for XIPE GPD instrument. A publication is being prepared on the pros and cons of each gas filling solution.

Lines of work and objectives for next year

The main lines of work and tasks are divided in activities in the framework of 1) AHEAD; 2) ProtonRadCdTe project; 3) IXPE mission activities:

1- H2020 AHEAD project reaches its end by February 28th. A new AHEAD 2 is being prepared including the same partners on two new mission concepts. AHEAD activities support our participation in the All-Sky-ASTROGAM ESA mission proposal and AMEGO NASA proposal.

1.1- Submission of AHEAD 2 proposal to Integrating Activities for Advanced Communities H2020 Call (INFRAIA-01-2018-2019) on March 22nd. On the framework of AHEAD 2, i-Astro will participate in two new mission concepts: CubeSat gamma-ray detector (CGRD) development and Laue lens based Narrow Field Telescope (NFT) (< 1 MeV) focal plane polarimetric optimization. Proposal approval will be public by July and AHEAD 2 may start by the end of 2019;

1.2 - Double layer CdTe polarimeter prototype will be further tested under an unpolarized beam (to calibrate measurements with polarized beam) up to 300 keV at LARIX facility. Measurements of a Laue lens response to the LARIX beam will be also performed. Further improvements will be performed in this protype;

1.3 – Enhanced All-Sky-ASTROGAM Phase-2 proposal should be submitted by March 20th. On the framework of proposal writing tasks our group will perform a detailed polarimetric study of mission's main instrument based on Si Double-Sided Strip Detectors (DSSD) tracker and a CsI calorimeter. Candidate mission will be selected by 2020 February;

1.4 – On the framework of AMEGO proposal development, i-Astro will contribute to the elaboration of several white papers concerning the scientific polarimetric potential of the mission, performing mass model simulations with MEGAlib simulation tool. These white papers will be submitted to NASA in the first semester of 2019, in order to trigger the next Medium-Class Explorers (MIDEX) Missions call. The objective is to submit AMEGO to this MIDEX call.

2- In the ProtonRadCdTe project our group will continue the evaluation of the proton radiation hardness in CdTe detectors exposed to a complementary proton energy band from 15 to 200 MeV, to best mimic the LEO proton energy spectrum.

3- In the 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 is being developed to measure electron cloud diffusion, in order to cross check with simulation results.

Medium-term (3-5 years) prospects

The i-Astro Group 2019-24 research plan consists on the development of innovative concepts to address the most relevant issues inhigh-energy astrophysics within three mission proposals: All-Sky-ASTROGAM, AMEGO and IXPE. Our group's task is to contribute to set and optimize the configuration of All-Sky-ASTROGAM and AMEGO missions, based on a combined detector set of DSSD (double-sided strip detectors) Si tracker and CsI and CdTe calorimeters. In particular, a solution for pair production polarimetry measurement will be studied and developed based on this kind of instruments. Such a solution will allow for the first space pair production regime polarimetric measurements, as well as optimal Compton polarimetry, providing a much wider gamma-ray polarimetry window (up to ~30 MeV) with a vast scientific potential on high-energy astrophysics.

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 on the development of a new gas mixture for the main instrument X-ray detector.

Further innovative concepts will be developed in the framework of the high-energy astrophysics activities of H2020 AHEAD project. In AHEAD 2, we expect to design and develop new gamma-ray detectors for high energy astrophysics, with polarimetric capabilities for the future CubeSat mission concepts, since the European Commission is supporting such low-cost platforms for space science missions. This work package will be named: "Advancing high energy astrophysics in the multi-messenger era using Nanosat platforms for in-orbit demonstration".

SWOT Analysis

Strengths and Opportunities

The group is a partner of three major international projects in high-energy astrophysics: H2020 AHEAD, All-Sky-ASTROGAM mission candidate (ESA F call) and AMEGO NASA proposal. Our participation in these consortia results from our expertise on high-energy astrophysics polarimetry for more than one decade, both in simulation and experimental testing. AHEAD activities provide institutional and technical links (simulation tools, detector technology and scientific facilities) that improve our research potential. In case All-Sky-ASTROGAM will be selected for launch in 2025, 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 ESA. The same prestigious launch opportunity might serve the AMEGO mission in the future MIDEX NASA call.

Spin-off 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 the PRODEX space oriented call. Collaboration in the framework of student training has been already established with the Active Space company and further future student thesis will include collaboration with this and other companies. Over the 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.

Publications

4 Articles in international journals

(with direct contribution from the team)

- ***"Inflight Proton Activation and Damage on a CdTe Detection Plane"***, N. Simões, J. M. Maia, R. M. Curado da Silva, S. Ghithan, P. Crespo, S.J.C. do Carmo, Francisco Alves, M. Moita, N. Auricchio, E. Caroli, Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 877 (2018) 183-191
- ***"Hard X-ray and Soft Gamma Ray Polarimetry with CdTe/CZT Spectro-Imager"***, E. Caroli, M. Moita, R. M. Curado da Silva, S. Del Sordo, G. de Cesare, J. M. Maia and M. Páscoa, Galaxies, Vol. 6, no. 3, 69 (2018)
- ***"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
- ***"Science with e-ASTROGAM"***, A. De Angelis, Tatischeff, V., (...), R. Curado da Silva (...) et al, J.High Energy Astrophys., Vol. 19, pp. 1-106 (2018)

1 International Conference Proceedings

- ***"The e-ASTROGAM gamma-ray space observatory for the multimessenger astronomy of the 2030s"***, V. Tatischeff et al., PROC SPIE 10699 (2018) UNSP 106992J

Presentations

2 Poster presentations in international conferences

- André Cortez: ***"e-Astrogam Mission Polarimetric Optimization"***, 2018-09-05, Ricap18 - 7th Roma International Conference on Astroparticle Physics, Roma Tre University, Italy
- Rui Curado Silva: ***"Future Gamma-ray Missions' Polarimetric Prospects"***, 2018-11-14, IEEE Nuclear Science Symposium, Sydney, Australia

1 Presentations in national conferences

- José Escada: ***"Otimização do meio gasoso dos GPD da missão ixpe/nasa"***, 2018-09-10, ENAA 2018, Observatório Astronómico da Universidade de Coimbra

1 Poster presentations in national conferences

- André Cortez: ***"Polarimetric Optimization of High-energy Space Telescopes"***, 2018-10-10, ENAA 2018, Observatório Astronómico da Universidade de Coimbra

5 Outreach seminars

- Rui Curado Silva: ***"Como Ser Astronauta"***, 2018-02-06, , Agrupamento de Escolas da Sé, Lamego
- Rui Curado Silva: ***"Como Ser Astronauta"***, 2018-05-08, , Escola Cristina Torres, Figueira da Foz
- Rui Curado Silva: ***"Como Ser Astronauta"***, 2018-09-13, , Rotary Club, Figueira da Foz
- Rui Curado Silva: ***"Como Ser Astronauta"***, 2018-10-30, , Escola Dr. Pedrosa Veríssimo, Paião
- Rui Curado Silva: ***"Astronomia & Tecnologia Espacial no Quotidiano"***, 2018-12-14, Astronomia & Tecnologia Espacial no Quotidiano,

Organized Events

1 Conferences

- ***"XXVIII Encontro Nacional de Astronomia e Astrofísica"***, [Conf] 2018-09-10 / 2018-09-11, Observatório Astronómico da Universidade de Coimbra

1 Collaboration Meetings

- ***"AHEAD WP9 Progress Meeting Coimbra"***, [Coll-Mtg] 2018-04-18 / 2018-04-19, Departamento de Física, Universidade de Coimbra

1 Outreach Events

- ***"Coimbra Space Summer School 2018"***, [OutR] 2018-09-12 / 2018-09-14, Observatório Astronómico da Universidade de Coimbra

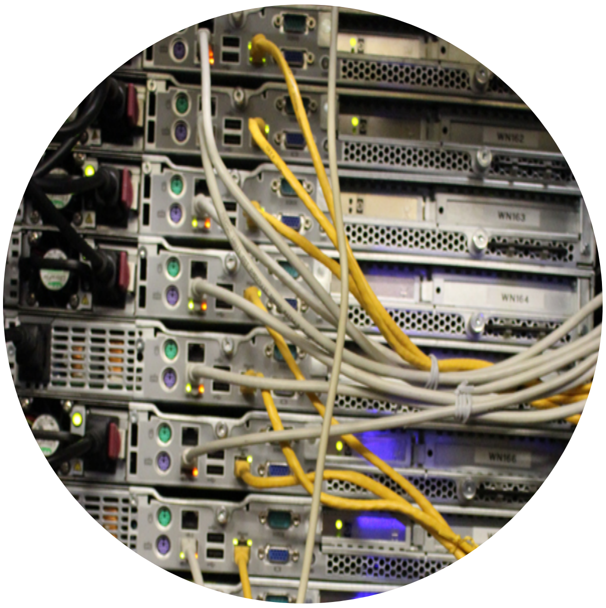
Theses

2 PhD

- Miguel Moita: ***"ASTROGAM Space Gamma-ray Telescope Main Instrument Development"***, 2015-01-01 , (ongoing)
- Alexandre Fonseca Trindade: ***"Study of noble gases mixtures characteristics as a detection medium"***, 2017-01-01 , (ongoing)

1 Master

- Marcela Páscoa: ***"Análise da deterioração das características de um protótipo de CdTe para um Telescópio Espacial de Raios Gama em ambiente de radiação orbital"***, 2016-10-01 / 2018-03-31, (finished)



[Computing]

GRID - Distributed Computing and Digital Infrastructures
Advanced Computing

GRID

Distributed Computing and Digital Infrastructures

Principal Investigator:
Jorge Gomes (100)

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7 *Technician(s):*
Carlos Manuel (100), Dinis Monteiro (92), Henrique Carvalho (46), Hugo Gomes (100), José Aparício (100), Nuno Ribeiro Dias (100), Samuel Bernardo (19)

5 *External collaborator(s):*
André Vieira, Catarina Ortigão, Isabel Campos, João Machado, Zacarias Benta

Total FTE:
11.0

Article(s) in international journals:
4 Direct contribution
Internal note(s):
5 Collaboration note(s)
International conference(s):
3 Oral presentation(s)
International meeting(s):
6 Oral presentation(s)
National conference(s):
5 Oral presentation(s)
Collaboration meeting(s):
3 Oral presentation(s)
Seminar(s):
2 Seminar(s)

Executive summary

The LIP distributed computing and digital infrastructures group provides information and communications technology (ICT) services to LIP and its research groups. The group operates institutional services, including compute and data services for simulation and analysis that support LIP's research. These services include the Portuguese Tier-2, a compute and data intensive facility integrated in the Worldwide LHC Computing Grid (WLCG). WLCG is a global collaboration of more than 170 computing centres in 42 countries, linking up national and international grid infrastructures.

In parallel the group is now delivering scientific computing services to the wider Portuguese scientific and academic community in the context of the Portuguese National Distributed Computing Infrastructure (INCD). These activities bridge at international level with the European Grid Infrastructure (EGI), Iberian Grid Infrastructure (IBERGRID) and European Open Science Cloud (EOSC). Also in this context the group collaborates with several research communities beyond High Energy Physics.

The development of the group competences and capabilities is also backed by the participation in R&D projects at national and international level. The group participates in European projects related to the development and application of distributed computing technologies (EOSC-hub, DEEP-Hybrid-DataCloud). The current R&D activities are focused on distributed data processing using cloud computing, high throughput computing, and high performance computing.

Sources of funding

Code	Amount	Dates	Description
INCD 01/SAICT/2016 - nº 022153	223.000 €	2017-07-18 / 2019-12-31	Portuguese National Distributed Computing Infrastructure
DEEP-HybridDataCloud - Grant 777435	362.500 €	2017-11-01 / 2020-04-30	Designing and Enabling E-Infrastructures for intensive Processing in a Hybrid DataCloud
EOSC-hub grant 777536	338.687 €	2018-01-01 / 2020-12-31	Integrating and managing services for the European Open Science Cloud
EOSC-synergy grant 857647	433.000 €	2019-09-01 / 2022-02-28	European Open Science Cloud – Expanding Capacities by Building Capabilities

Total: 1357.187 €

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Lines of work and team organization

The team is organized in four areas:

- Scientific computing and data processing, including 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 projects. Enabling the development of advanced competences and services. 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, digital preservation, and software quality assurance, among others.
- Core institutional services covering support to administrative services, WAN and LAN, network related services, desktops, laptops, security, authentication and authorization, printers, data protection among 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. R&D pushes the evolution of the services and infrastructures delivered by the group, while the services and infrastructures themselves support and enable the R&D activities.

Stated objectives for past year

LIP IT Services

- Continue adoption of cloud and container based solutions.
- Complete deployment of IT infrastructure at LIP Lisbon.
- Adapt to the European General Data Protection Regulation (GDPR).

WLCG and Tier-2

- Improve capacity by exploiting existing cloud resources.
- Seek solutions to improve the Tier-2 and address obsolescence.
- Evaluate solutions to replace current batch scheduling system.

INCD

- Execute the INCD national infrastructure project.
- Increase the capacity of the INCD cloud.
- Collaboration with thematic infrastructures.
- Collaboration with the national HPC network.

EGI, IBERGRID and EOSC

- Liaise the INCD infrastructure with the European Grid Infrastructure (EGI).
- Common IBERGRID participation in EGI and IBERGRID operations coordination.
- Coordination of software Configuration, Change, Release and Deployment management activities in EOSC-hub.
- Integration and operation of the OPENCoastS thematic service in EOSC.

INDIGO-DC

- Joining the INDIGO-DC software collaboration agreement.
- Participation in the DEEP-HybridDataCloud project coordinating the pilot services and software lifecycle activities, and supporting accelerated computing and HPC for machine learning and data analysis.

Achievements and responsibilities during the past year

In 2018 the Tier-2 has delivered 68,274,317 normalized (HEPSPEC06) processing hours to ATLAS and CMS. The equipment with 10 years of continuous intensive use exhibited a steep increase of hardware problems that affected the Tier-2 capacity and reliability.

In December 2018 the National Distributed Computing Infrastructure (INCD), of which LIP is a partner, started to deploy new hardware for its cloud computing service. The European public tender as well as the installation and commissioning of this equipment is being performed by LIP. Profiting from this opportunity a large fraction of the acquired capacity was temporarily added to the Tier-2 to perform the validation and acceptance of the hardware. This enabled to fulfill the Tier-2 pledge during the last weeks of the year.

The INCD activities increased significantly. New dissemination activities and new users resulted in an increase of usage that exhausted the existing resources.

LIP 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. The EGI middleware coordination was again performed by LIP, IFCA and CESGA in the context of the IBERGRID collaboration.

The EOSC-hub project joining EGI, EUDAT and the INDIGO-DC consortium was approved and started in January 2018. The project is establishing the basis for the European Open Science Cloud (EOSC) initiative of the European Commission. 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 is collaborating with LNEC to develop OPENCoastS, a thematic service to deliver wave and ocean circulation forecasts for the European Atlantic coast. The OPENCoastS service is now operational and a tutorial organized in December 2018 had more than 100 participants from Europe and elsewhere.

The INDIGO-DC software agreement was signed joining the partners of the INDIGO-DataCloud project aiming at the maintenance of the software and participation in new projects (LIP, INFN, DESY, KIT, CSIC, CERN, CESNET, CNRS, STFC, CEA and others). Also within the INDIGO-DC context, LIP continues 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 virtualization, accelerators and layered networks.

The udocker tool developed and maintained by LIP in the context of INDIGO-DC is now being funded by EOSC-hub and has more than 450 stars on github.

LIP in the context of the INCD and IBERGRID activities has organized the 2018 edition of the international conference Digital Infrastructures for Research (DI4R). The conference joined EGI, Géant, PRACE, EUDAT and OpenAIRE and counted with more than 400 participants. In parallel, LIP also organized the 2018 edition of the IBERGRID conference co-located with DI4R.

Lines of work and objectives for next year

LIP computing services

Finalize the deployment of the LIP Lisbon datacenter at 3Is and reorganize the Lisbon ICT facilities accordingly. Improve the IT services and internal network within the available budget. Reorganize the repositories for documentation and software. Extended federated authentication to all possible services. Implement a user registration and self service portal.

WLCG and Tier-2

In collaboration with INCD, renew the Tier-2 infrastructure services including a new Lustre storage system and a new batch system based on Slurm. Adapt the Tier-2 to exploit the INCD cloud computing service. Reorganize the Tier-2 network taking advantage of new network equipment provided by INCD. Implement WLCG recommendations that were pending to the lack of resources. Continue working with the LIP management and the LHC groups to seek a solution to address the existing Tier-2 and Tier-3 shortcomings.

INCD

Continue executing the INCD P2020 project. LIP will continue improving and operating the cloud, HPC and HTC and storage services provided by INCD. Finish the deployment of the new hardware acquired in December 2018. Deploy a new OpenStack platform, new Ceph storage system and jointly with the Tier-2 activities renew the batch system and associated storage. Deploy a new HPC service equipped with low latency network.

In the context of the Portuguese advanced computing network, integrate some of the Stampede capacity offered by TACC in the INCD infrastructure. Preparatory work will be conducted at LIP Minho by two INCD collaborators using a minimal Stampede hardware setup made available by FCT. This will constitute the basis for an INCD point of presence in Minho.

Continue the collaboration with other national thematic infrastructures such as BioData, PORBIOTA, CoastNET, GBIF and their international counterparts Elixir, LifeWatch and others, new collaborations will be pursued.

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. The middleware coordination in EGI will be ensured by IBERGRID via LIP, IFCA, UPV and CESGA.

Continue the participation in the EOSC-hub, that joins EGI, EUDAT and INDIGO-DataCloud. Coordinate the software Configuration, Change, Release and Deployment management activities in EOSC-hub for all cloud, grid and data oriented services. Continue evaluating the EUDAT data management solutions now in collaboration with INCD. Supporting the udocker tool developed by LIP in EOSC-hub. This will become the basis for a national scientific data repository pilot in collaboration with FCT-FCCN.

Jointly with LNEC continue developing and operating the OPENCoastS thematic service in EOSC-hub providing on-demand forecasts for the European Atlantic coast. The service will be further enhanced and its high-availability improved in partnership with IFCA.

The new H2020 project EOSC-synergy, will promote the development and adoption of the EOSC services by scientific users in several European countries and the convergence of the corresponding national infrastructures. The project will be coordinated by CSIC and LIP.

INDIGO-DC and DEEP-Hybrid-DataCloud

Exploit further opportunities for collaboration with the INDIGO-DC consortium partners. In this context, continue the DEEP-Hybrid-DataCloud project that is developing solutions for large scale deep learning and post-processing in cloud and HPC environments exploiting specialized hardware accelerators and low latency. LIP is coordinating the software quality assurance, release management and infrastructure. LIP is also participating in R&D to further explore Linux containers and full virtualization in cloud and HPC environments.

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 in 2020-2021. The objective until then is to position INCD so that it can apply for further funding from the national research infrastructures roadmap. INCD is also expected to operate a small fraction of the Stampede supercomputer that has been offered to Portugal by TACC, and whose access will be granted by FCT through a new type of project calls.

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 such as life sciences, biodiversity, and others. The European Open Science Cloud also offers new opportunities for collaboration that will be explored, including provisioning of OPENCoastS, creation of new services, and participation in new projects.

LIP will continue exploiting synergies with other organizations especially in the context of INCD, aiming at collaboration in the development, deployment and operation of platforms and solutions adapted to the needs of these user communities. Examples are GBIF, LifeWatch/PORBIOTA, Elixir/BIODATA and CoastNET.

The INCD program of work foresees the creation of competence centres dedicated to specific topics, and similar approach is likely to be adopted by the Portuguese advanced computing network. LIP will exploit such opportunities.

SWOT Analysis

Strengths

- Extensive knowledge and experience in scientific computing.
- Excellent international relations and integration in scientific e-infrastructures.
- Operating the Portuguese WLCG Tier-2 under the CERN LHC computing MoU.
- Strong partnership with FCCN and LNEC via INCD.
- Participation in the FCT infrastructures roadmap.
- Users from multiple disciplines and organizations.
- Participation in major e-infrastructure European projects.

Weaknesses

- Hardware obsolescence and lack of processing and storage capacity.
- Cash flow issues are compromising the execution of the INCD funding.

Opportunities

- Maintain and improve the computing farm 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.

Threats

- Lack of resources is badly affecting the WLCG Tier-2 and the existing infrastructure.
- Lack of coherent national policies for scientific computing and digital infrastructures.
- Lack of funding for operational costs.

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Publications

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

- *"Running high resolution coastal models in forecast systems: moving from workstations and HPC cluster to cloud resources,"*, João Rogeiro, Marta Rodrigues, Alberto Azevedo, Anabela Oliveira, João Paulo Martins, Mário David, João Pina, Nuno Dias, Jorge Gomes, Advances in Engineering Software, Volume 117, 2018, Pages 70-79, ISSN 0965-9978, https://doi.org/10.1016/j.advengsoft.2017.04.002
- *"Enabling rootless Linux Containers in multi-user environments: the udocker tool"*, Jorge Gomes, Isabel Campos, Emanuele Bagnaschi, Mario David, Luis Alves, Joao Martins, Joao Pina, Alvaro Lopez-Garcia, Pablo Orviz, Computer Physics Communications, Volume 232, 2018, Pages 84-97, ISSN 0010-4655, https://doi.org/10.1016/j.cpc.2018.05.021
- *"INDIGO-DataCloud: a platform to facilitate seamless access to e-infrastructures"*, D. Salomoni , I. Campos, L. Gaido, J. Marco de Lucas, P. Solagna, J. Gomes, et al, J Grid Computing (2018) 16: 381. https://doi.org/10.1007/s10723-018-9453-3
- *"umd-verification: Automation of Software Validation for the EGI federated e-Infrastructure"*, Pablo Orviz, Joao Pina, Álvaro López, Isabel Campos, Jorge Gomes, Mario David, J Grid Computing (2018) 16: 683. https://doi.org/10.1007/s10723-018-9454-2

5 Collaboration notes with internal referee

- *"A set of Common Software Quality Assurance Baseline Criteria for Research Projects"*, P Orviz (IFCA), A García (IFCA), C Duma (INFN), G Donvito (INFN), M David (LIP), J Gomes (LIP), DEEP-Hybrid-DataCloud project deliverable
- *"Pilot testbed and integration architecture with EOSC large scale infrastructures"*, Mário David, DEEP-Hybrid-DataCloud project deliverable
- *"First release of common services software"*, M Krakowian (EGI), B Kryza (CYFRONET), J Reetz (MPG), A Ceccanti (INFN), C Martens (DKRZ), M D'Antonio (CINECA), H Widmann (DKRZ), E Fernandez (EGI), C Condurache (STFC), J Gomes (LIP), A Tsaregorodtsev (CNRS), G Molto (UPV), M Antonacci (INFN), B Wilk (CYFRONET), P Orviz (IFCA), T Zok (PCSS), C Cacciari (CINECA), L Dutka (CYFRONET), EOSC-hub project deliverable
- *" First report on Thematic Service architecture and software integration"*, M Krakowian (EGI), 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,
- *" First Thematic Service software release"*, M Krakowian (EGI), 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

Presentations

3 Oral presentations in international conferences

- Jorge Gomes: *"Rootless containers with udocker"*, 2018-10-10, Digital Infrastructures for Research DI4R, ISCTE, Lisbon, Portugal
- Mário David: *"IBERGRID towards EOSC"*, 2018-10-10, Digital Infrastructures for Research DI4R, ISCTE, Lisbon, Portugal
- Jorge Gomes: *"IBERGRID status report"*, 2018-10-11, IBERGRID 2018 9th IBERIAN grid infrastructure conference, ISCTE, Lisbon, Portugal

6 Oral presentations in international meetings

- Jorge Gomes: *"Integration of HPC resources and techniques"*, 2018-01-21, New Challenges in Data Science: Big Data and Deep Learning on Data Clouds, Univ. Internacional Menéndez Pelayo, Santander, Spain
- Jorge Gomes: *"udocker"*, 2018-04-17, EOSC-hub week 2018, Malaga, Spain
- João Pina: *"Updates from IBERGRID"*, 2018-04-17, EOSC-hub week 2018, Malaga, Spain
- Jorge Gomes: *"IBERGRID Infrastructure and User Communities"*, 2018-05-07, Portuguese - Spanish Workshop on Research and Education Networks and E-Science , University of Salamanca, Spain
- Mário David: *"INCD for the researchers"*, 2018-10-26, Computation in Science@UAlg, Universidade do Algarve, Faro, Portugal
- Jorge Gomes: *"e-Infrastructures and how can we use them"*, 2018-12-13, OPENcoastS e-Tutorial: from processes knowledge to on-demand circulation forecasts, LNEC, Lisbon, Portugal

5 Presentations in national conferences

- Jorge Gomes: *"LIP computing services and infrastructures"*, 2018-02-16, LIP Workshop 2018, Evora, Portugal
- Jorge Gomes: *"LIP computing and IT services"*, 2018-03-16, Data science in (astro)particle physics and the bridge to industry Symposium, LIP, Lisbon, Portugal
- Catarina Ortigão: *"INCD - Computação para a Ciência e para o Ensino"*, 2018-04-12, Jornadas de Computação Científica 2018, INL, Braga, Portugal
- Jorge Gomes: *"Iberian distributed computing infrastructure"*, 2018-07-02, Ciência 2018, Lisbon Congress Center, Lisbon, Portugal
- Jorge Gomes: *"INCD - Computação para a Ciência e para o Ensino"*, 2018-09-27, Workshop "Summer Innovation Campus", Universidade de Trás-os-montes e Alto Douro (UTAD), Vila Real, Portugal

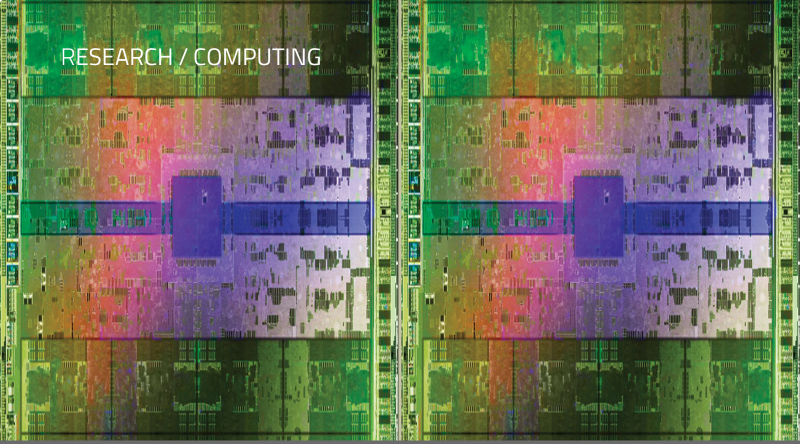
2 Seminars

- Jorge Gomes: *"Lightweight Computer Virtualization "*, 2018-01-18, LIP seminars, LIP, Lisbon, Portugal
- Jorge Gomes: *"INCD - Computação para a Ciência e para o Ensino"*, 2018-10-18, Seminar at Instituto Dom Luiz, FCUL, Lisbon, Portugal

Organized Events

2 Conferences

- *"Digital Infrastructures for Research 2018 (DI4R)"*, [Conf] 2018-10-09 / 2018-10-11, ISCTE, Lisbon, Portugal
- *"IBERGRID 2018 9th Iberian grid infrastructure conference"*, [Conf] 2018-10-11 / 2018-10-12, ISCTE, Lisbon, Portugal



ADVANCED COMPUTING

Principal Investigator:
António Pina (75)

2 *Master Student(s):*
Bruno Ribeiro (100), Tiago Duarte (8)

3 *External collaborator(s):*
António Esteves, José Rufino, Vítor Oliveira

Total FTE:
1.8

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 currently 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;
- advanced training: Linux, Concurrent C++.

Achievements and responsibilities during the past year

The work developed closely followed the objectives set for the year 2018. However, the recent change in the scientific role played by the national Polytechnic Institutes has resulted in the loss of one of the members of the group and a significant reduction on the participation of second element. In this circumstance, until being able to make the group grow in number of members we will have some limitations to cover larger projects. 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-going MSc thesis aimed to support the efficient processing of data in the context of project “BigDataHEP: Understanding Big Data in High Energy Physics”;
- start of a new Msc thesis project related to the “Distributed Training of Deep Neural Networks”;
- third edition of the course, “The Basics of the LINUX Command Line” in UMinho;
- LIP-Minho summer internships -- Linux/C++ e Root, UMinho;
- installation and support to a new CPU/GPU Linux platform dedicated to Machine Learning evaluation ;
- maintenance and administration of the local computer cluster infrastructure

Lines of work and objectives for next year

In 2019, 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 plan to upgrade the current local Rocks Cluster infrastructure to the new version and continue to support the local 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”.

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.

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;
- Use of the Advanced Computing Center (MAAC) that will be hosted at UMinho may significantly extend the potential for processing large amounts of scientific data.

Threats

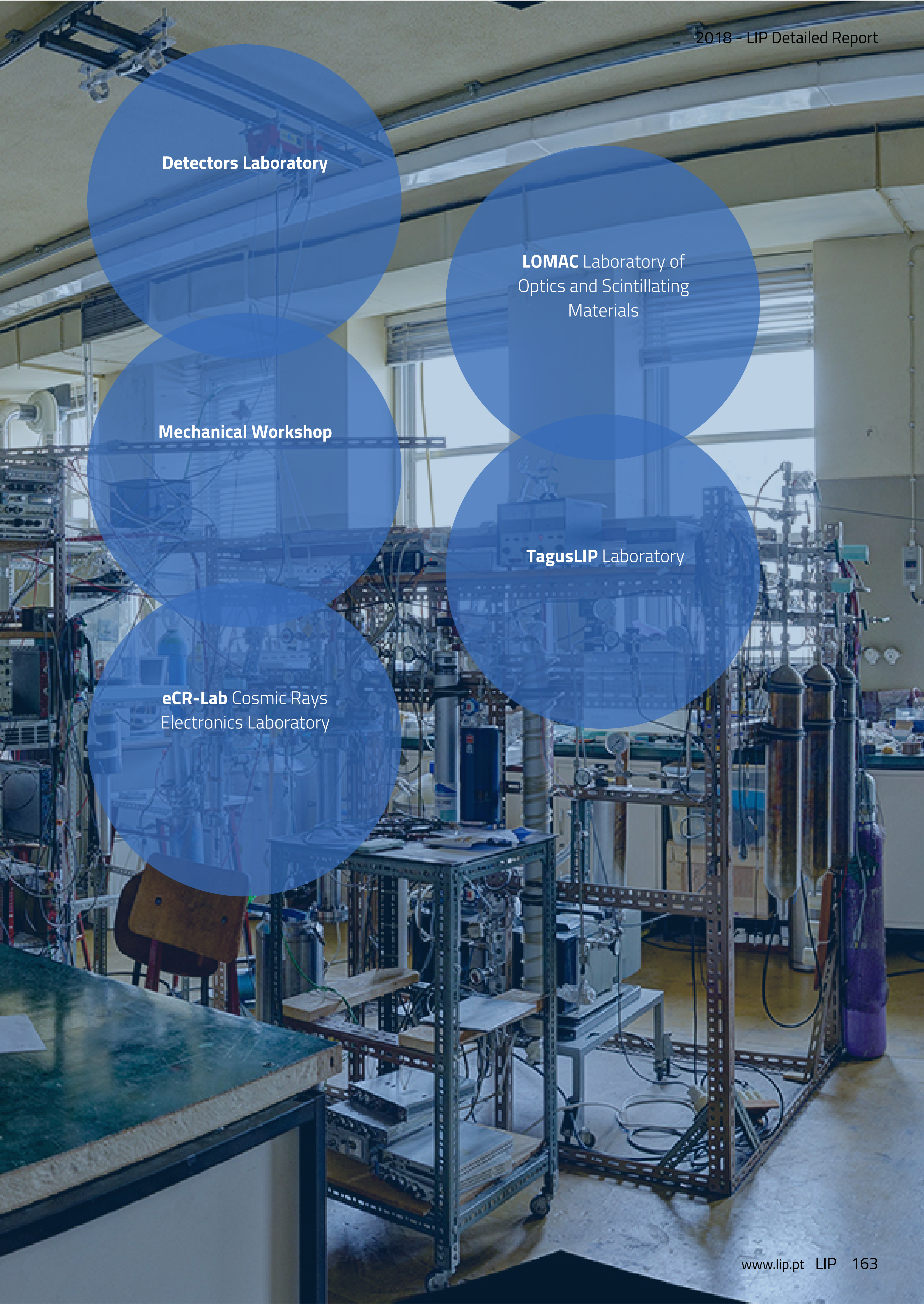
- Local HPC infrastructure has no guarantee of continuity of service by lack of financial support for equipment maintenance/upgrade and system administration;
- In Portugal, there are no unemployed graduates in Computer Engineering. In this context, it is very difficult to attract to scientific work young people, without the availability of funds, to support new scholarships for MSc or PhD.

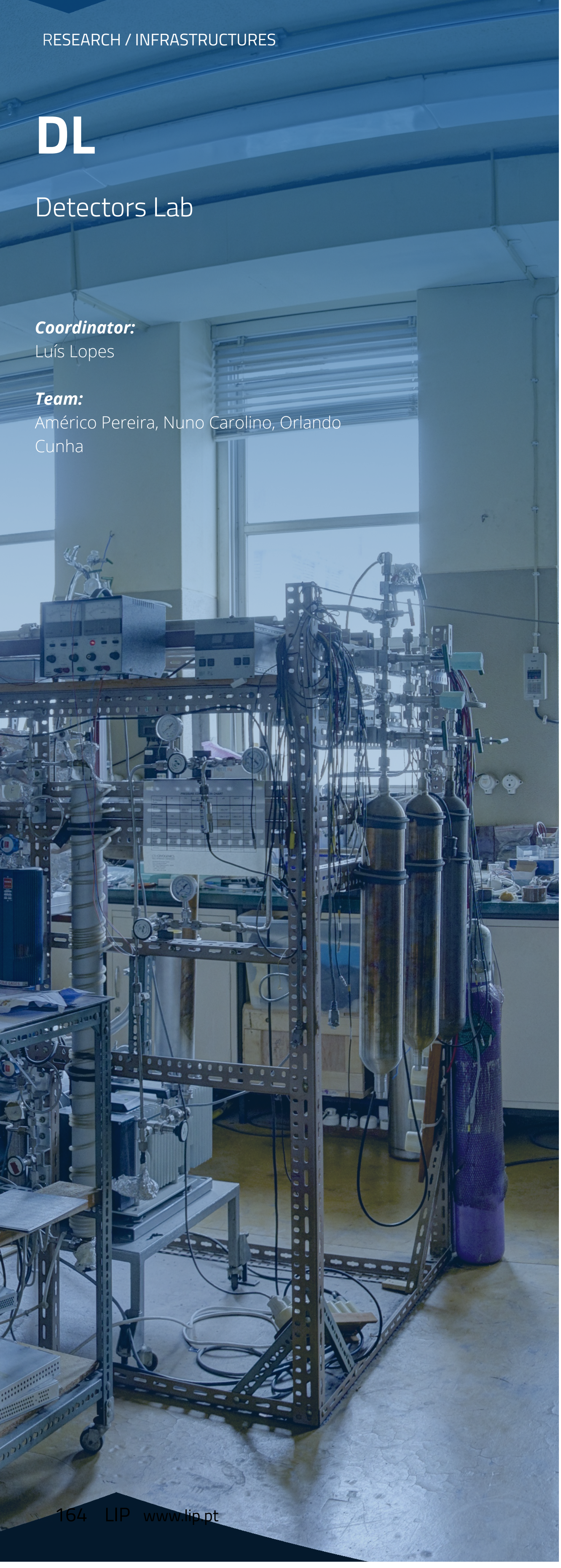
Theses

1 Master

- Bruno Ribeiro: ***"PlaCor: Plataforma para a Computação Orientada ao Recurso"***, 2017-10-02 , (ongoing)

RESEARCH Facilities


Detectors Laboratory
LOMAC Laboratory of Optics and Scintillating Materials
Mechanical Workshop
TagusLIP Laboratory
eCR-Lab Cosmic Rays Electronics Laboratory



DL

Detectors 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 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 60% of the foreseen area is available for our activities. In 2018, no additional space was liberated and practically no improvements were made. The installation should be finalized in 2018. Currently available are a medium clean room for the assembly of sensitive parts of the detectors, a room for painting and another with a simple cutting machine used to prepare all the non metallic parts used in the production. Most of the mandatory instruments and tools are available in adequate quantity and quality.

Detectors 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, HADES and Antarctica. Our contribution is multidisciplinary, once we almost fulfil all the needed branches: 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 total during 2018 were build more than 80 m^2 including timing and trigger (counting) detectors. This activity consumes around 40% of our total manpower. For a more detailed description of our contribution to these projects, should be consider that we develop from zero the detector sensitive volume, the gas control and monitoring system and 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 2018, this consumed about another 40% of our human resources. We contributed with technical work and added value in the following projects: Animal-PET, SNO+, Spark Chamber, CriostatoLaserlab-DQUC, LZ (system upgrade), HADES, AIDA2020, SINE2020, Cloud Chamber, GSPC.LIP, OrthoCT and muTT/Tomuvol. Besides detector work, this included the layout, loading and testing of PCBs home made electronic boards.

More technical, management-related contributions 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.

Completely new activities were those related to direct contract for the provision of services and products by the DL to external clients. In total this corresponded to 5-7% of our manpower and returned a considerable income (more than 25% of the annual staff cost).

The first prototypes of a sealed RPC were built and successively improved. We expect to produce the first detector within 2019

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!

We expect the production of large area RPCs to be lower this year. We will: finish the HADES-FD and MuTom; start the STRATOS production. 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.

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 version 2 of the Animal-PET; RPCs for neutrons within SINE2020; RPCs for high rate applications within AIDA2020; a second unity of the system for SNO+ calibration; finalization of the CriostatoLaserlab for the Chemistry Department of the Univeristy of Coimbra; Cloud Chamber; GSPC.LIP; HADES and SHiP.

There will, in addition, be R&D contributions for several projects, namely HADES-MDC and LATTES RPCs. The sealed RPC will for sure became an usable detector. This is a major development, even more the context of global warming issues.

We also plan to maintain or increase the weight of the work contracts with external groups.

Overal, 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 taks. 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 50 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 stayed more less as it was in 2018, and it seems very complicated to achieve significant improvements in that point.

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. Other 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 owrk. We systematic 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. Projects such as muTT and Antarctica will allow these products to be based on a "market segment" that can have a very significant return to the Organization. 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 30 k€ in direct contract of DL products and services for external groups, including research centres, 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.

MW

Mechanical Workshop

Coordinator:
Alberto Blanco

Team:
Carlos Silva, Douglas Lima, Nuno Filipe Silva Dias, Rui Alves

Brief description of the 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 (two technicians and two engineers) allow the MW to perform a large spectrum of mechanical services, from the project to the production and testing. Today, the MW provides services not only to the CERN projects but also to research groups, inside and outside LIP, and to external companies.

The work developed by the MW and by LIP's Detector Laboratory (DL) is fully complementary, and most of the work developed at LIP needs the competences from both facilities. Three decades of experience make very clear that, in the absence of these two facilitiees, 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 responsabilities in international collaborations. (CP-LEAR, DELPHI, HERA-B, ATLAS, HADES, AUGER). Equally evident are the benefits to the national R&D community, at local and national level.

Workshop

Activities and achievements during the past year

2018 has been a year with many projects (around 60) and 100% of the time occupied. Here a list of the main (consuming more than 5% of the human resouces) production projects:

- Construction, assembling and test of a second unit of the Umbilical Retrieval Mechanism (URM) (mechanics for the PMT calibration system) for the SNO+ experiment. 37 % (1539 H/m and 831 H/M). Not finished yet.
- Construction of a test chamber, pieces for gas systems and several small pieces of general purpose for the Physics Department of the University of Coimbra. 14 % (583 H/m, 354 H/M).
- Construction of parts for RPC detectors for the LIP-Auger group in the frame work of the project "A new generation of RPC muon detectors for high-precision high-energy cosmic-shower", namely: gas bubblers, gas connectors, electronic supports, HV PS boxes and auxiliary mechanical parts. 9,9 % (414 Hours/man, 443 Hours/Machine).
- Construction of Mechanical Supports for the LIP-LZ group. 5.2% (216 H/m, 122 H/M).
- Construction of the mechanics for a second RPC Preclinical-PET scanner. 5.4% (222 H/m, 125 H/M).
- Relocation of the infrastructures, maintenance and management. 10.8% (449 H/m, 84 H/M)
- Other projects. Support and construction of mechanical parts for the following groups and entities: DL, LATTES, Gamma Cameras, SHiP, Gaseous Detectors R&D, HADES, RPC R&D (Antarctica), i-Astro, ATLAS, Portuguese Institute of Oncology (IPO), Chemistry Department (DQ), Outreach, and other small works 17,8 % (741 H/m, 417 H/M).

Plan for next year

Many projects are already allocated for 2019 fulfilling almost (or maybe more than) 100% of the MW capability. Significant efforts are been made to hire new staff, but for the moment without success. The most significant projects are:

- Finalization of: second unit of the Umbilical Retrieval Mechanism (URM) (mechanics for the PMT calibration system) for the SNO+ experiment; mechanics for a second RPC Preclinical-PET scanner and two Spark Chambers for outreach.
- Construction of two Cloud Chambers for outreach.
- Construction of the mechanics for the new RPC detectors for HADES.
- Construction of the sub-pressure box for LATTES.
- Construction of the mechanics for the muon tomography project.
- Construction of a new chamber for testing new structures of gas amplification.
- Construction of mechanics for the first STRATOS station.
- Finalization of the relocation of the MW to the new infrastructures that started in the end of 2016. Due to the work load during 2017 and 2018, this activity was relegated to a second plane to give priority to the running projects.
- Installation and start-up of a new CNC machine. The MW will be equipped with a new CNC machine of large area (3x2m) especially devoted to the construction of large area detectors.

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:

- One of our technicians will leave LIP in 2020, therefore we need to find a replacement for him. This has already started but without success.
- We want to uniform the software tools that we use both in project and production. The use of different tools leads to many small but complicated and annoying problems. In this line, we want to connect all the old CNC machines to our CAN software which will improve performance.
- Consolidate the relocation of the MW once and for all, in order to really profit of the new space.

  Installation of the new machine with 3x3 m² working area and exploration of all its capabilities.
  Continue to outsource work (when possible) in order to absorbs working peaks (something that has already started but not very often used). We need to create a good relationship with neighbouring companies.

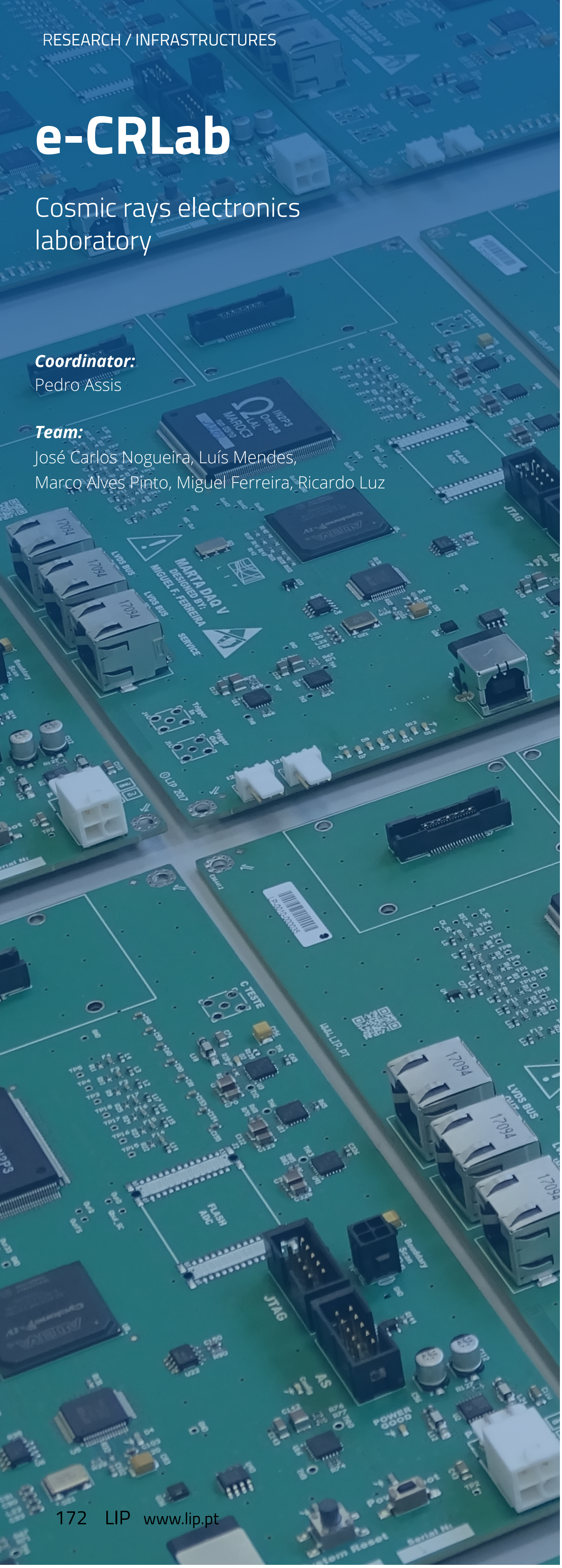
SWOT Analysis

Strengths & Opportunities

- Valuable know-how, experience and skills of the technical staff.
- Valuable partnership with the DL.
- 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 opens 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.



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 put on fast digital electronics implemented in FPGAs. The laboratory has the capability to design complex printed circuit boards and to produce simple PCB prototypes. The production of complex PCB and its assembly is outsourced. There is 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, and two instrumentation rooms with state-of-art equipment, and with the capability to produce PCBs. A small mechanical workshop for detector prototypes development and a dark room are available to complement and support our activities.

e-CRLab

Activities and achievements in the past year

The e-CRLab has given a very large contribution to the MARTA project. The front-end of the system was designed at the laboratory and during this last year the produced boards were tested, reworked where needed, and shipped to Brazil for further assembly. The e-CRLab also had the responsibility to design and produce support systems for MARTA such as the Low Voltage Power Supply Unit (PSU). The Central Unit of the system is being developed based on a development board from Intel based on a hybrid system coupling a microprocessor to an FPGA (SOC-FPGA). The monitoring and control system of MARTA is also being developed following the approach taken by Auger. This work is being developed as part of a master thesis.

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 developed using the MARTA DAQ. The Gianni Navarra setup was upgraded to allow precision studies of the water Cherenkov detector and a new hodoscope was implemented to test the upgrade scintillator detectors.

During the summer an internship started the work to instrument a gaseous volume fabricated in Coimbra. The resulting RPCs were integrated in a muon hodoscope to be used in muon tomography. The Laboratory was responsible for the system integration and has developed the support mechanics in the mini-workshop.

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 to test the degradation with accumulated radiation doses. This work, developed in the framework of internships of 3 students, will be continued as a master thesis.

The e-CRLab also provided support for teaching and outreach activities, mainly by developing and maintaining experimental setups.

Plan for next year

Next year will be critical for the deployment and comissioning of the developed systems. Namely, we expect to be able to deploy the MARTA engineering array. This will require a great effort to finalize and debug all the systems. Moreover it will also be critical to assure the correct operation of the hodoscope systems deployed in Auger. Studies on the performance of the RPCs are expected to be conducted in close collaboration with th eRPC group and the Detector Laboratory infrastructure.

We expect that 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 plan to continue the support to teaching activities with the development and operation of cosmic ray related experimental setups. We also foressee to give support to the Laboratory of Radiation and Atomic Physics at IST by introducing cosmic ray setups and by upgrading the electronics, whenever possible.

The studies of radiation damage are of key importance and will be pursued in close connection with the SpaceRad group.

Medium-term (3-5 years) prospects

The infrasture plans to secure its acquired competence in front-end, DAQ and digital electronics, as well as in system integration. In this period the operation of MARTA and contributions to the muon tomography and LATTES will be of key importance. We will pursue a closer connection with the RPC R&D group, developing and implementing DAQ systems for other projects within the RPC R&D group.

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.

SWOT Analysis

Strengths

The competences acquired in digital logic design as well as the competence in the design of complex electronic systems. Competence in handling several types of detectors such as RPCs, scintillators coupled to photomultipliers and Silicon Photomultipliers. Activities developed in the context of research projects. Capability to develop characterization systems. Possibility to plan and perform irradiation campaigns.

Weaknesses

Up to now it was not possible to attract direct funding for the development of detectors. The level of funding is incompatible with the full development of detectors. Some equipment need to be upgraded to face growing time resolution demands. The lack of portable equipment limits the activity in off-premises experimental setups. Need to be more efficient in publishing of the work developed.

Opportunities

The MARTA engineering array will give the opportunity to lead the development of a medium size project end-to-end. LATTES poses a mid-term opportunity to consolidate activities. The radiation damage studies present the possibility to attract students and funding through the SpaceRad group. Training activities, courses lectured in e-CRLab and master thesis developed in e-CRLab can allow to increase manpower in the laboratory and allow to pursue different projects.

Threats

Financing is always a key issue when developing hardware that needs to spend in service acquisition and materials. Lack of man power could also be an issue in the mid-term.

LOMaC

Laboratory of Optics and Scintillating Materials

Coordinator:
Agostinho Gomes

Team:
Amélia Maio, João Gentil,
Luís Gurriana, Luís Seabra,
Ricardo Gonçalo

Brief description of the facilities

LOMaC was created for the test and preparation of WLS fibres for the ATLAS TileCal project in the 1990s, with human resources and expertise from CFNUL, LIP, FCUL, and UNL. The entire WLS fibres set for the ATLAS TileCal has been polished, aluminized and quality controlled at LOMaC. LOMaC's expertise is centered on the preparation and test of plastic WLS and scintillating optical fibres, scintillator plates and related devices to be used in high energy and nuclear physics detectors. The LOMaC facilities and setups are the following:

Facility to cut/polish bundles of optical fibres; Optical fibre aluminization facility (by magnetron sputtering); Fibrometer – automated device for the characterization of sets of up to 32 optical fibres; Mono-fibrometer – automated device for the characterization of individual optical fibres; 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 SNO+ calibration system; WLS fibres for W104/Icarus muon tagger; WLS fibres for Tilecal gap/crack scintillators upgrade. LOMaC also studied the light output and uniformity of scintillators for TileCal, having designed the optical masks to improve their uniformity, and tested a set of PMTs also for TileCal. It also gave crucial support to the development of the plastic profiles that house the WLS fibres in the TileCal calorimeter.

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

Scintillators with the sizes and shapes foreseen for a tile calorimeter for the Future Circular Collider (FCC) were characterized in the Tilemeter, in a first contribution for this long term R&D. The scintillators and WLS fibres used are the ones of the ATLAS TileCal and the scintillators are cut to size and polished at LIP's Meachanical Workshop in Coimbra.

During the past year, the fibrometer got damaged and required intervention to replace one faulty sensor and to repair moving parts, in a delicate operation that required to disassemble and assemble the longitudinal movement section.

The aluminization facility faced also problems in its hardware. One turbopump and its controller started showing an inefficient performance (stop-start during normal operation and data corruption). This pump is being kept off implying a reduction of the pumping capacity of the system but still being able to reach the vacuum pressure optimal for the sputtering process. The pressure gauges controller stopped working and a replacement was purchased.

Together with the setup to cut/polish the bundles of fibres using a lathe that belongs to the DEGGE department from FCUL and located at the FCUL workshop, several sets of fibres were prepared for aluminization. The aluminization setup was used to put aluminium on the top of the fibres obtaining good quality mirrors.

After the repair of the fibrometer and the aluminization system, a set of almost 3000 Kuraray Y11 WLS fibres was aluminized for the upgrade of the ATLAS TileCal gap/crack scintillators.

The study of the response stability of the calibration optical fibres of the SNO+ detector submerged in water was started in collaboration with the LIP SNO+ group.

Late in the year part of the equipments that were not needed for the preparation of the fibres for TileCal were moved to the new LIP laboratories and the respective setup started.

Setups like the tilemeter and the mono-fibrometer have been used in several educational and outreach activities. LOMaC participated in the LIP Summer Internship program.

Plan for next year

Most of the planned production activities are related to the upgrade of ATLAS and they include:

- Tests of orange WLS fibres, to be used with green scintillators. These sets are expected to be radiation harder than the scintillators used in the old Minimum Bias Trigger Scintillators (MBTS).
- Preparation of sets of WLS fibres to be used with new scintillators for the MBTS. Due to the large radiation doses expected in these scintillators, some of them will be replaced by radiation harder green scintillators.
- Scintillator-WLS fibres couplings tests.

There is work in progress to improve the performance of the fibrometer and decrease systematic effects. Due to the ageing of the equipment and the recent failure, it is necessary to evaluate the status of the different components and prepare a plan for upgrade. If resources are available, the design of a new flexible system for the characterization of scintillators and fibres will be done.

For the next year a collaboration with the LIP Dosimetry Group is foreseen, for the characterization of scintillating optical fibres for applications in microdosimetry

Additionally there is work in progress in the characterization of scintillators with the sizes and shapes that are foreseen for a tile calorimeter for the FCC, and this will be continued. This will involve the preparation of a test setup using SiPM readout of the tile scintillation light.

The transfer of the aluminization equipments and the fibrometer for the new laboratories will take place in the second half of the year.

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. This year LOMaC will participate in the effort for the replacement of the Minimum Bias Trigger Scintillators with preparation of WLS fibers of several types. In the following years 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 discussion 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 oportunity to participate in new detectors in HEP or related fields.

Threats

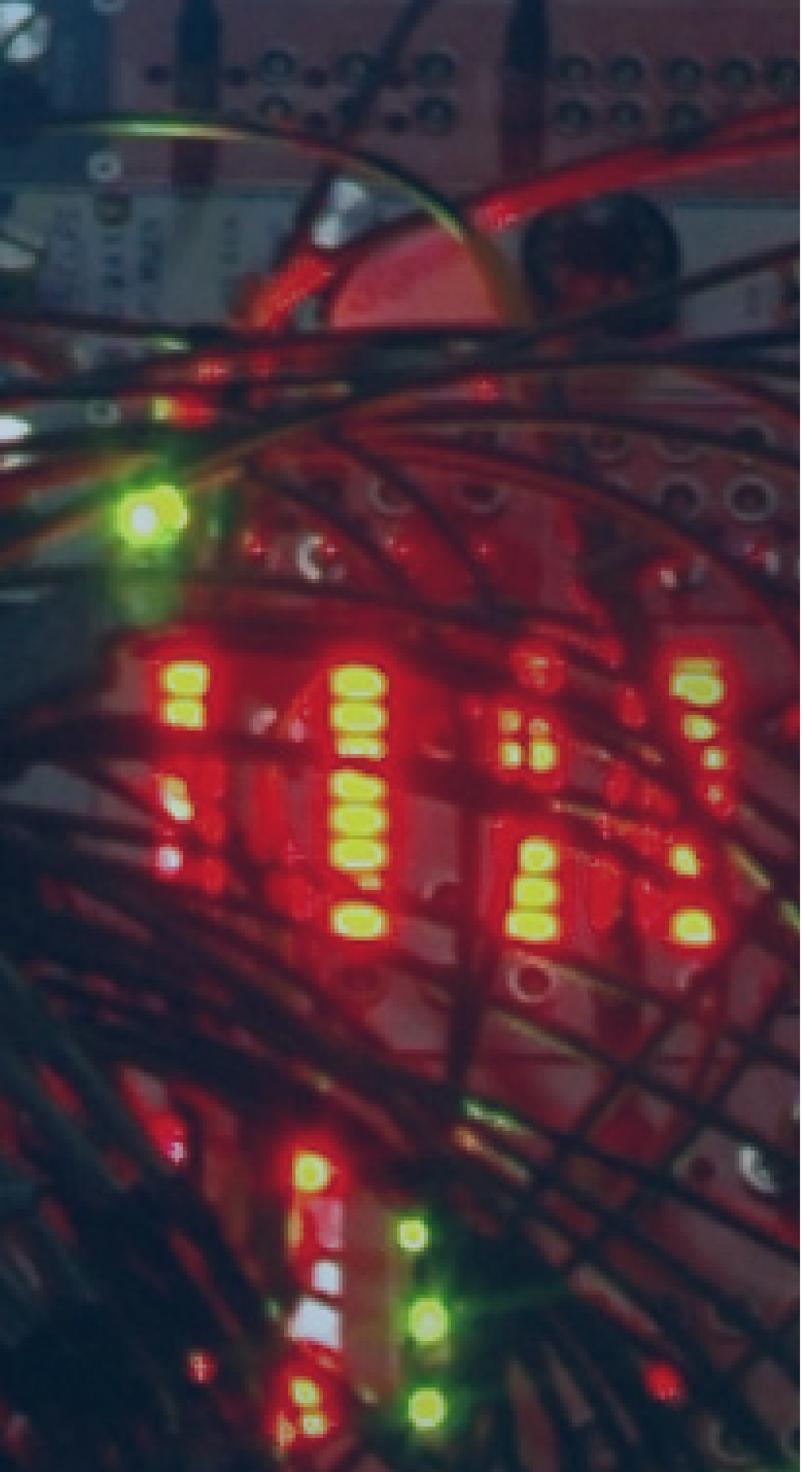
Lack of financial resources. Up to now we had more requests than we could handle. In the future we do not know. Lack of sustained operations in future is possible.

TagusLIP

TagusLIP Laboratory

Coordinator:
João Varela

Team:
Luis Ferramacho, Miguel Silveira, Rui Pereira da Silva, Tahereh Niknejad



Executive summary

The TagusLIP Laboratory is a LIP research infrastructure installed in 2004 at the Lisbon Science and Technology Park (Taguspark). The campus is home to a University (IST), several research centres as well as a large spectrum of startups and PMEs.

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. The TagusLIP has a computing and data storage infrastructure, suitable to software projects in various areas, such as data acquisition, equipment control, data analysis and image processing. The TagusLIP is licensed for the use of radiation sources needed to develop and test new instruments in nuclear medicine.

The research teams that traditionally have been using TagusLIP have large experience in the development, commissioning and operation of large electronics and data acquisition systems 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

TagusLIP laboratory

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 startup 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 5 years to develop considerably its activities and to become a main contender in the market of readout electronics for photosensors. PETsys Electronics developed a new ASIC for SiPM readout (TOFPET2) with increased performance, and developed also complete SiPM readout and data acquisition solutions for detector systems with tens of thousand channels. PETsys Electronics has customers in four continents, America, Europe, Asia and Australia, and in 2018 had sales exceeding 1 M€. Most of the sales correspond to small test systems with the TOFPET2 ASIC. Nevertheless, seven PET scanner prototypes with PETsys Electronics technology are being built by five companies, some of which have already decided to adopt PETsys Electronics technology.

Activities and achievements in the past year

In 2018 the main users of the TagusLIP Laboratory were the LIP research groups CMS and STCD and the startup company PETsys Electronics. The following activities have been performed:

LIP CMS and STDC groups

1. Specification of a new ASIC for the CMS MIP Timing Detector, in the frame of the Phase II Upgrade of the CMS experiment for HL-LHC. System simulations of the TOFHIR2 ASIC performance under the MTD/BTL operation conditions. Particular attention was given to the impact of radiation on the SiPM performance and dark noise. The study of filtering algorithms capable to reduce the impact of dark noise on the timing resolution was undertaken.
   Development of the TOFHIR1 test system.
   Development of a PET detector module with DoI and Timing capability for large PET scanners.

PETsys Electronics

1. Characterization of the performance of the ASIC TOFPET2 for special applications as requested by costumers.
2. Development and characterization of the Ball Grid Array (BGA) package of the TOFPET2 ASIC. Development of in-house test system of ASICs in BGA packaging.
3. Organization of the production, testing and supply of PETsys Electronics products.
4. Development of a DAQ concept for Full Body PET with 500 k channels, in collaboration with LIP.
5. Microelectronics design of the TOFHIR1 ASIC following the specifications of the LIP-CMS group. The chip is derived from TOFPET2 and introduces new features in particular the possibility of operation at very high signal rate. The design was delivered to the CMS Collaboration in July 2018. The TOFHIR1 chips were received from the foundry in December 2018.

The results obtained were presented at several international conferences, including Full Body PET-Ghent 2018 and IEEE/NSS/MIC 2018 in Sydney.

A collaboration with the PANDA experiment has been established. The PANDA experiment at the future Facility for Antiproton and Ion Research (FAIR) requires excellent identification of subatomic particles. For this purpose, a Detector for Internally Reflected Cherenkov light (DIRC) is being developed at the University of Giessen. The working principle is based on detecting single photons by Microchannel Plate Photomultiplier Tubes (MCP-PMTs). Because of the high time resolution, small form factor and scalability, the PETsysElectronics TOFPET2 ASIC was chosen as the favored readout option. The current prototype setup which was recently tested at CERN used more than 1000 channels. The final detector will consist of 28,800 channels.

PETsys Electronics was listed among Medical & Health IT as one of the top 25 Portuguese emerging start-ups for 2018 in the Scale-up report. This dynamic Scale-up report is a ground-breaking study of the top 25 emerging Start-ups in Portugal, selected by considering the total funding received and total revenues of all start-ups with Portuguese origin, with less than 5 years of operation (i.e. between 2012 & 2017).

Plan for next year

The LIP-CMS group and the company PETsys Electronics will be the main users of the TagusLIP Laboratory in 2019. Due to the lack of dedicated funding, the activities of the LIP STCD group on medical applications is reduced to the integration of students benefiting from independent funding.

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. Test of the TOFHIR1 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.
2. Development 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.

The development of the new ASIC TOFHIR2 is pursued in collaboration with PETsys Electronics. PETsys Electronics is responsible for the microelectronics ASIC design and the LIP-CMS group develops the integration of the chip in detector modules. Both activities make use of the TagusLIP laboratory infrastructure.

PETsys Electronics

The activities of PETsys Electronics in 2019 include:

1. Full validation of the new data acquisition system based on the TOFPET2 ASIC. New capabilities have been introduced in the system, in particular a distributed Coincidence Trigger, high-speed optical links (6 Gb/s), and new options for SiPM bias voltage generation.
2. Large scale production tests of components and systems supplied by PETsys Electronics.
3. Development of dedicated frontend electronics for the PANDA experiment.
4. Development of the second version of BTL ASIC TOFHIR in radiation tolerant CMOS 130 nm technology of TSMC (TOFHIR2). The development of the TOFHIR2 chip is achieved by translating TOFHIR1 to the CMOS 130nm technology provided by TSMC, that is less sensitive to radiation, and by revising the TOFHIR1 blocks for radiation tolerance. Important functionality related to SiPM dark noise cancellation not existing in TOFHIR1 is also implemented in TOFHIR2. The first MPW submission of TOFHIR2 is foreseen in the Q3 2019.

Publications

2 Articles in international journals

(with direct contribution from the team)

- ***"Design and characterization of the readout ASIC for the BESIII CGEM detector"***, Fabio Cossio, Maxim Alexeev, Ricardo Bugalho, Junying Chai, Weishuai Cheng, Manuel Dionisio Da Rocha Rolo, Agostino Di Francesco, Michela Greco, Chongyang Leng, Huaishen Li, Marco Maggiora, Simonetta Marcello, Marco Mignone, Angelo Rivetti, Joao Varela, Richard Wheadon, PoS TWEPP-17 (2018) 044
- ***"Experimental results with TOFPET2 ASIC for time-of-flight applications"***, Ricardo Bugalho et al. (14 authors), Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 912 (2018) 195-198

Theses

1 PhD

- Tahereh Niknejad: *"Development of new high-performance Positron Emission Mammography based on new photosensor technology"*, 2013-10-01 / 2018-02-28, (finished)

COMPETENCE CENTRES

Monitoring and Control Competence Center

Simulation and Big Data Competence Center

CCMC

Competence Center in Monitoring and Control

Coordinator:
Francisco Neves

Team:
Filipe Veloso, João Silva

Overview

The Competence Center 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 benefit 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's activities

- The CCMC started the development of a complete software framework intended to be used as the basis solution when deploying our products. The software was 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:

- For the group ECOTOP from the MARE-UC institute, the CCMC started the development and implementation of non-invasive devices for the monitoring of the temperature and heart rate of birds during nesting in their natural habitat.

Prospects for next year

For the next year, the CCMC plans to:

- Finish 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;
- Field testing of the device for monitoring the temperature and heart rating of birds before the final product delivery (schedule for mid March);
- Install an environmental monitoring system for the server room at LIP-Coimbra;
- 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

- A large body of knowledge accumulated from the participation of LIP members in several experiments, often with direct responsibilities in the development, constructions and maintenance of monitoring and control subsystems.

Weaknesses

- Do not have (explicitly) allocated FTEs or resources for the procurement and project development and integration with the other LIP infrastructures.
- The current inability to certificate LIP product and services.

Opportunities

- The ability to deploy very high quality products and services developed within scientific projects and meeting very high quality and reliability standards at competitive prices.

Threats

- The ability to meet deadlines and ensure the manpower required for the assistance to services/products contracted with third party entities and it potential impact in the LIP image.

SIMULATION & BIG DATA

Competence Centre on Simulation and Big Data

Coordinator(s):
Nuno Castro, Bernardo Tomé

Team:
Alexandre Lindote, Ana Peixoto, António Pina, Bruno Galhardo, Bruno Ribeiro, Celso Franco, Daniel Galaviz, Diogo Gonçalves, Filipa Peres, Filipe Veloso, Giles Strong, Guilherme Milhano, Henrique Carvalho, Juan P. Araque, Korinna Zapp, Liliana Apolinário, Luisa Arruda, Marco Alves Pinto, Miguel Fiolhais, Patrícia Gonçalves, Paulo Brás, Paulo Crespo, Raul Sarmento, Ricardo Barrué, Rui Curado Silva, Tiago Duarte, Tiago Vale, Vladimir Solovov

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 two years ago and the first priorities were the identification of the technical competences mastered by the LIP members in these two areas, establishing communication and discussion forums, starting a training program and establishing an action plan for the next few years.

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, where the Geant4 toolkit is extensively used.
- In the context of one of these courses, a simulation tool for the description of virtual experiments in the context of the teaching of Nuclear Physics laboratories, started to be developed. An oral contribution was presented by the students at the National Physics Conference.
- The participation in the Geant4 collaboration was continued. Developments to one Advanced Example, for which LIP is responsible, were included in the last Geant4 release.
- Support to the needs of LIP research groups was provided. In particular, the generic simulation framework of the muon tomograph to be installed in the Lousal mine was implemented using Geant4.
- Several developments in the context of the activities of the LIP groups were also undertaken. In particular:
    - The GUIMesh tool, for the conversion of STEP files (the standard CAD exchange format) to GDML files, compatible with Geant4, was developed by the Space Rad group. This work was accepted for publication in Computer Physics Communications.
    - In the framework of O-PGI (orthogonal prompt-gamma imaging) for monitoring particle radiotherapy, a multi-leaf collimator has been fully optimized by Geant4 simulation and self-developed reconstruction routines. The obtained results were published in Physica Medica.

The Big-Data branch of the competence center developed the following activities:

- Sucered three funded projects in the big data area: FCT PTDC/FIS-PAR/29147/2017 (started July 2018), COST action CA17137 (started September 2018) and STRONG-2020 (INFRAIA 01 Advanced Communities H2020 call, funding to start in 2019).
- Opening of a call for a researcher in machine learning (project BigDataHEP).
- Installation of new computer servers with GPUs in Minho and Lisbon.
- Organization of the 1st School and Symposium “Data Science in (Astro)Particle Physics: the Bridge to Industry”, Lisbon, March 2018.
- Regular informal meetings with all the interested LIP members, which include topical discussions and tutorials.
- Ongoing collaborations between members of different LIP groups (ATLAS, CMS, Auger, LATTES, Dark Matter, Phenomenology) in the context of machine learning.
- Collaboration with Bosch Car Multimedia in the context of the iSci-Bosch-ECUM project.

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 contribution to the Geant4 collaboration will be continued as well as the support to the needs of the LIP groups. The development of the simulation tool for a virtual Nuclear Physics laboratory will be continued and, hopefully, it will start to be used in the context of teaching activities. Within the i-Astro participation in All-Sky-ASTROGAM and AMEGO mission proposals, a set of validated mass model simulation tools (Geant4 and MEGAlib), including polarimetry up to 50 MeV, will be provided to the high-energy astrophysics community. The ongoing activities concerning the implementation of a proton therapy facility in Portugal should start to be more closely followed, identifying areas where the Competence Center can bring its expertise.

On the Big Data side, the ongoing funded projects will allow to expand the LIP competences in machine learning, as well as to hire dedicated human resources through contracts and grants. This, together with the dedicated computing resources recently acquired, will potentiate the possibilities to have common projects in data analysis within the different LIP groups, to consolidate the skills and experience of the LIP members in modern machine learning tools and to expand our training program in this area.

The second edition of the Data Science School and Symposium will be organized in March 2019 in Braga (University of Minho). The ongoing survey of the competences in data science by other portuguese groups will be continued, aiming to identify potential collaborations and consolidate 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, two years ago: expand LIP's competences in this area by exploiting synergies between the different groups, implement a training program and establish partnerships with the academic and industrial communities interested in this field.

SWOT analysis

Strengths

- Long standing expertise in simulation and big data at LIP.
- Expertise in modern data mining techniques used in HEP and beyond.
- Integration in international collaborations (HEP experiments, Geant4 collaboration).
- Recently funded projects in machine learning.

Weaknesses

- Despite some progresses in 2018, the different efforts ongoing at LIP in this field are not yet fully integrated.
- Despite having more researchers and students working in this field, we are still below the critical mass in some areas.

Opportunities

- Huge interest and demand for expertise in simulation, big data and data mining.
- 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 a 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.

Threats

- These areas are extremely competitive, involving a community much larger than the HEP community.
- Dispersion of efforts in areas where we cannot be competitive.
- Difficulty in providing external services.

Simulation & Big Data

Publications

1 Articles in international journals

(with direct contribution from the team)

- *"Search for pair and single production of vectorlike quarks in final states with at least one Z boson decaying into a pair of electrons or muons in pp collision data collected with the ATLAS detector at root s=13 TeV"*, ATLAS Collaboration (2924 authors), Phys. Rev. D 98 (2018) 112010

1 Articles in international journals

(with indirect contribution from the team)

- *"Machine Learning in High Energy Physics Community White Paper"*, J.P. Araque, N. Castro et al. (118 authors), J.Phys.Conf.Ser. 1085 (2018) no.2, 022008

Theses

1 PhD

- Tiago Vale: *"Search for vector-like quarks in Zt/b+X events at ATLAS"*, 2016-09-13 , (ongoing)

4 Master

- Diogo Gonçalves: *"Machine Learning in Analytical Chemistry: Applying Innovative Data Analysis Methods Using Chromatographic Techniques"*, 2017-09-01 , (ongoing)
- Filipa Peres: *"New observables and techniques for the study of jets in hadron collisions"*, 2018-09-15 , (ongoing)
- Tiago Duarte: *"Treino de redes neuronais profundas de forma distribuída"*, 2018-10-01 / 2019-09-30, (ongoing)
- João Pedro Gonçalves: *"Topic modelling for jets"*, 2018-11-01 , (ongoing)

Sources of funding

Code	Amount	Dates	Description
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: 924.187 €

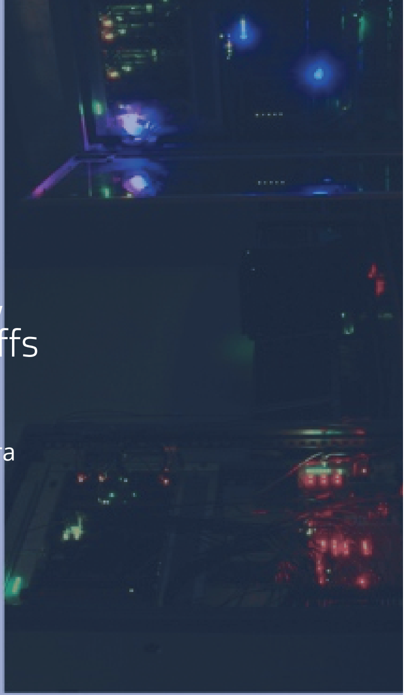
Science and Society

Knowledge transfer, industry and spin-offs

Radiation, health and environment

Advanced training

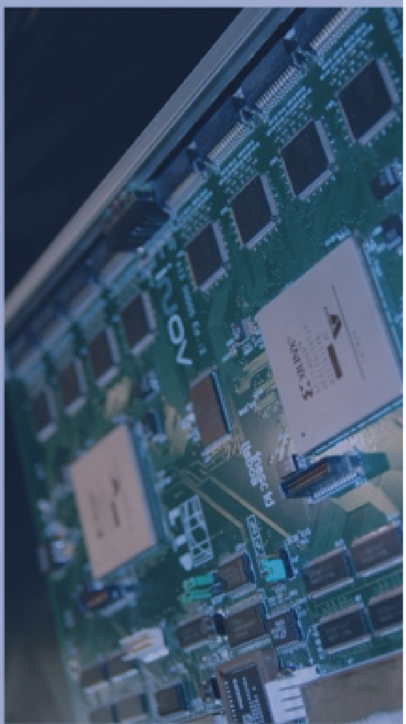
LIP-ECO Education, communication and outreach

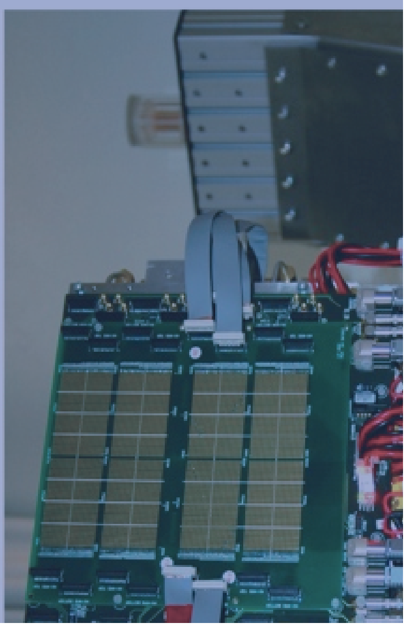


TT

Knowledge Transfer, Industry and Spin-offs

Coordinator: Gaspar Barreira





Overview

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 the next few year, LIP will remain instrumental in creating opportunities for Portuguese industry at CERN and in other scientific infrastructures, in the context of their industrial procurement rules. In particular, the LHC-HL upgrade constitutes a unique opportunity for collaboration between LIP and industry.

Particle physics technologies have a wide range of applications, and the potential to respond to societal changes. LIP aims at boosting our shorter term societal impact through specific research lines dedicated to applications to health care and space exploration. Scientific computing is certainly one of the areas placing particle physics at the forefront of innovation. LIP co-leads the National Infrastructure for Distributed Computing, serving the Portuguese scientific community at large.

TT

2018 Activities

Direct transfer

Knowledge transfer to companies occurs across the whole spectrum of LIP's activities. Highlights on knowledge transfer opportunities in 2018 are listed below:

- LIP had contracts or was in consortia with EFACEC SA, EVOLEO SA, PETsys Electronics, HYDRONAV SA, Nu-Rise, ICNAS-Produção, Cabelte and BOSCH
- The development of TOFPET1 ASICs for PET Time-of-Flight applications was at the origin of the creation of the startup company PETsys Electronics in 2013. 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 TagusLIP operation costs are presently shared between LIP and PETsysElectronics. Benefiting from the infrastructure available at TagusLIP, PETsys Electronics was able in the past 5 years to develop considerably its activities and to become a main contender in the market of readout electronics for photosensors. PETsys Electronics was listed among Medical & Health IT as one of the top 25 Portuguese emerging start-ups for 2018 in the Scale-up report. A LIP PhD student completed her thesis in the context of this close collaboration.
- In 2018 the activities of the LIP CMS and ATLAS groups towards the Phase 2 Upgrade for operation at HL-LHC entered in full swing following the approval by FCT and the Minister of Science and Technology of the participation of LIP in the Phase 2 Upgrade of both experiments. The ATLAS-LIP group tested at CERN the first HV distribution cables with reduced profile produced by the Portuguese company Cabelte. Aluminization of t2500 WLS optical fibers for the instrumentation of the TileCal gap counters and tests of the first prototype of HV distribution board (HVRemote) were done at LOMaC. In CMS, the development of the front-end ASIC (TOFHIR) was pursued in collaboration with the PETsys start-up. PETsys is responsible for the microelectronics ASIC design and the LIP-CMS group develops the integration of the chip in front-end boards and detector modules.
- A 4-layer TOFtracker device has been constructed, integrated and deployed, for muon tomography of cargo containers at harbours, for the HYDRONAV S.A company.The STRATOS project for the construction of two cosmic ray telescopes for the monitoring of the stratosphere temperature was submitted by HYDRONAV in cooperation with LIP. The system is a prototype for a future macro-scanner for cargo container scans. The project was recommended for funding.
- LIP's RPC-based small animal PET scanner currently operating at ICNAS with a world-record resolution, and is at pre-commercial development stage; a human-brain scanner is a priority for the next years. During the year 111 mice examinations were carried out with the aim of supporting research at ICNAS. Steps have been taken to upgrade the detectors and mechanics to final pre-commercial device. A project for the construction of a Brain PET was submitted to the C2020, in cooperation with ICNAS-Produção and IPC.
- The collaboration with the Nu-Rise company allowed the development of a fiber dosimeter for clinical staff in intervention cardiology. The purpose of this dosimeter is to make real-time dose monitoring of the clinicians performing intervention cardiology under fluoroscopy. The first hospital tests will take place in 2019 in Hospital de Santa Maria, Lisboa. Collaborations at national level with INESC in the development of a microdosimeter and in microdosimetry studies with CTN will be established. This is in line with the strategic plan of LIP regarding future research in the projected installation of a hadron therapy unit in Portugal.
- LIP's space activities are based upon collaboration with industry, contracts with European Space Agency, participation in consortia (LIP is member of the EUROPLANET consortium http://www.europlanet-eu.org) for H2020 calls (currently EFACEC and EVOLEO). There are agreements with space related companies to collaborate in the next call for projects, specially the PRODEX space oriented call. Collaboration in the framework of student training has been already established with the Active Space company.
- The LIP computing group has extensive knowledge and experience in scientific computing, excellent international relations and integration in scientific e-infrastructures, with users from multiple disciplines and organizations, participates in the FCT infrastructures, and in the enabling of future policies for scientific computing and open access. This creates the potential for industrial and e-government applications, and the possibility of engagement with other communities.
- LIP's scientific infrastructures and competence centers provide support to our activities but also services to external entities. In 2018, 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 the industry. The Simulation and Big Data Competence Center organized two workshops on "Data Science in (Astro)Particle Physics: the Bridge to Industry" and is part of several European Consortia, in particular a COST action. A collaboration with Bosch Car Multimedia in the context of the iSci-Bosch-ECUM project is ongoing.The Monitoring and Control Competence Center is providing services do other research institutes at the University of Coimbra.
- The work on electron beam applications for Food Irradiation" within the NUC-RIA group will be reinforced during 2019.
- LIP is committed to the Open Science paradigm and present in the Portuguese scientific open access platform.

Industrial liaisons

LIP's involvement with CERN has triggered technological transfer to Portuguese industry through contracts awarded by CERN. 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 the next few year, LIP will remain instrumental in creating opportunities for Portuguese industry at CERN and in other scientific infrastructures, in the context of its industrial procurement rules. In particular, the LHC upgrade constitutes a unique opportunity for collaboration between LIP and industry.

In mid 2018, the industrial liaisons officer (ILO) mandated to support and actively promote national industry and R&D institutions to CERN, ESO, ESRF left FCT. His effective replacement is of the highest importance to ensure a positive industrial return to Portugal,

Portuguese traineeship programme at CERN, ESA and ESO

since several years LIP supports the FCT programme "Advanced training of engineers in the International Organizations - CERN, ESA and ESO", in 2018 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 defined by FCT), helps disseminate the calls, particularly through our networks and partner universities and participates in the selection process of the candidates. The process following the 2017 call was quite delayed and only 4 candidates signed the contract to work at CERN within this programme. LIP helped to accelerate the preparation of the 2018 call, which was launched in October, allowing the selection process to start still in 2018. At the end of 2018, a 1-day Workshop was held at CERN, in which the trainees presented their work. A very positive feedback from their supervisors is testimony to the importance and success of this 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 bringing together leading European high energy physics research institutions: CEA, CERN, CNRS, CIEMAT, DEMOKRITOS, DESY, ELI-ALPS, ELI BEAMLINES, EPFL, ESS, GSI, IJS, IFIN-HH, INFN, INOVACENTRUM, KTN, LIP, NTUA, SOFIA University, STFC, TU of Kosice, University of Belgrade, WEIZMANN Institute and WIGNER; which work across a range of world-leading scientific areas in the field of Particle Physics, Astrophysics and Nuclear Physics.
To push back scientific frontiers in these fields requires innovation. It is challenging and costly to carry further research and development focused in applications, products and processes and turn them into commercial opportunities. HEPTech, as a source of technology excellence and innovation, 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; show and tell sessions; the Heptech Symposium. LIP, as an HEPTech node member, follows the various activities and maintains updated its awareness about knowledge and technology transfer and the paths for commercialization.
In 2018, José Carlos Silva has been appointed as the new LIP representative in HEPTECH. A steering committee meeting was held in which several changes to the network organization were approved. In particular, the roles of Chairman and President will be merged into a single person, the network leader, elected for two years (and one year in advance). Better mechanisms for interaction and communication between the network members will be put in place. In the meeting, the "excellent" contribution of LIP "in kind" was referred: one person working for the network for one year, who did an "outstanding job".

Prospects for 2019

LIP will continue to stimulate technology transfer by reinforcing its links with industry, in the development of detector systems for different applications, in computing, and in paticular in the areas of health and space applications. LIP's cientific infrastructures and competence centres will boost the collaboration with external partners. The close collaboration with ICNAS and CTN for technology transfer in the health sector, namely in radiotherapy instrumentation, imagiology and detector R&D. This has increased relevance in the context of the possible instalation of a proton therapy unit in Portugal. LIP's RPCs are well suited for a wide range of applications from security to geology and, most prominently, to health. In what concerns space applications, LIP is now a solid partner of ESA, and the goal is to boost the participation in ESA planetary missions, in consortia with Portuguese and European companies, which will boost inter-sectorial technology and knowledge transfer. LIP will be instrumental in creating opportunities for Portuguese industry at CERN and in other scientific infrastructures. In particular, the LHC upgrade constitutes a unique opportunity for collaboration between LIP and industry. The work in the upgrade will be intense in the next couple of years.

RADIATION, HEALTH AND ENVIRONMENT

Radiation, health and environment

Principal Investigator:
Luis Peralta (30)

4 *Researchers:*
Alina Louro (10), Conceição Abreu (30), Florbela Rêgo (10), Sandra Soares (80)

3 *PhD Students:*
Joaquim Pedro Kessongo (100), Margarida Isabel Inácio (100), Yoenls Bahu (100)

3 *Master Students:*
Ana Campos (7), Filipa Carvalho (3), Soraia Elísio (100)

2 *External collaborators:*
Patrick Sousa, Pedro Gabriel Almeida

Total FTE:
5.7

As this radioactive gas, abundant in granitic areas, is recognized as a carcinogenic agent, and is appointed by the World Health Organization as the second leading cause of lung cancer after tobacco smoke, the knowledge of its concentrations inside the houses is important from the point of view of radiological protection. In addition, Radon is the largest contributor for underground water radioactive pollution. Its concentration in water represents a public health risk due to the fact the gas can easily escape to the air, adding to the total radon indoor concentration. On the other hand, ingestion of water with a high radon concentration represents an additional risk for the stomach. In 2018 the group focused its work in the development of an Arduino controlled radon monitor and on the study of radon gas in the air and water. A radon detector based on a low-cost Si-PIN photodiode working in counter mode has been developed. The detector is mainly sensitive to alpha particles and has been successfully tested. Evaluation of radon concentration in water for human consumption were initiated in Bibala, a municipality in Angola, where granitic rocks are common, and contain a high concentration of uranium that can be mobilized on underground water was made. Measurements of radon concentration were performed on 26 water samples obtained on several depth drilled wells and analyzed with DURRIDGEs' RAD7 equipment. Nowadays several international organizations involved in radiation protection and public health, have produced new guidance, recommendations and requirements aiming better protection from radon exposure. With the new legislation, DL 108/2018 (Transposition of Basic Safety Standards COUNCIL DIRECTIVE 2013/59/EURATOM to national legislation) protection against indoor exposures to radon in both workplace and dwellings is clearly regulated and exposures to radon in dwellings are regulated for the first time. The LabExpoRad at Covilhã can provide radon measurement services for the comunity. For this, the certification of our laboratory services is in preparation.

Articles in international journals:
1 Direct contribution
International meetings:
1 Oral presentations
National conferences:
1 Oral presentations
Seminars:
2 Outreach seminars
2 Outreach seminars
Events:
4 Events organized

Radiation, health and environment

Lines of work and team organization

Presently the team has two lines of research:

1. Development of new instrumentation for radon detection, led by Luís Peralta

2. Measurements of radon in air and water, led by Sandra Soares

Stated objectives for past year

Development and test of low-cost radon detectors that can be deployed inlarge number in the Angola campaigns.

Campaigns in Angola to deploy CR-39 passive detectors for radon in air monitoring and to collect water for radon monitoring foreseen.

Achievements and responsibilities during the past year

A radon detector based on a low-cost Si-PIN photodiode working in counter mode has been developed. The detector is mainly sensitive to alpha particles and has been successfully tested. The signal from the photodiode is amplified and a digital signal produced for each signal with amplitude above threshold. The digital signal is then count and stored by the Arduino microcontroller. Data can be saved to a datalogger (memory card) or transferred to a computer.

The radon monitor based on a low-cost photodiode and with Arduino acquisition system was tested with success in a rich radon environment. Simultaneous measurements with a Geiger detector show similar counting variations along a time period of a month.

Water samples were collected between 2017 and 2018 at Bibala municipality (Angola). This is a pioneering study at the Bibala region, and the results are of importance for public health concerns. In order to measure radon concentration on water samples a RAD7 equipment was used, from Durridge using the RAD7 H2O option. This equipment has specific procedures that provide a direct reading of the water sample radon concentration. Measurements performed on 26 samples show that 5 of these have values over 100 Bq.L^{-1}, the recommend maximum value of directive 2013/51/EURATOM. Considering the results found on some sources of Bibala municipality we conclude that for a few of them water is not safe for immediate consumption being necessary to take preventive action like boiling water or wait before using the water until most of the radon has time to decay.

Lines of work and objectives for next year

Nowadays several international organizations, involved in radiation protection and public health, have produced new guidance, recommendations and requirements aiming better protection from radon exposure. With the new legislation, DL 108/2018, protection against indoor exposures to radon in both workplace and dwellings is clearly regulated and exposures to radon in dwellings are regulated for the first time. The LabExpoRad at Covilhã can provide radon measurement services for the comunity. In order to provide assurance to clients that radon measurement comply with standards, ethics and protocols, it is of the outmost importance the laboratory services become certified in this field. So, to achieve this quality we are preparing the certification of our laboratory services.

As this radioactive gas, abundant in granitic areas, is recognized as a carcinogenic agent, and is appointed by the World Health Organization as the second leading cause of lung cancer after tobacco smoke, the knowledge of its concentrations inside the houses is important from the point of view of radiological protection. So, in order to develop an epidemiologic study with the Portuguese Lung Foundation, another working line of this team will be the assessmente of radon concentration in areas previously identified with a potentially high level of residential 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.

The program will respond to current and future nuclear market needs for qualified nuclear engineers, technologists, radiation protection professionals and radiation protection experts. For example, by 2020, more than 100 nuclear reactors will be at a standstill in Europe and the number is expected to increase by 8% per year. Many professionals need to be re-qualified in this work context.

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.

Increased radon exposure has been associated with an increased risk of lung cancer. Almost all types of lung cancer are carcinomas and they are usually divided into two major groups: small cell lung carcinoma and non-small cell lung carcinoma cells. Small cell lung carcinoma accounts for about 20% of lung carcinomas and is closely related to tobacco. On the other hand, non-small cell lung carcinoma is divided into three types, according to the cells that comprise it: squamous cell or squamous cell carcinoma, adenocarcinoma and large-cell carcinoma cells. However, there are several different kinds of adenocarcinomas diagnosed that do not meet established standards. Some of them may be related to radon exposure. Thus, 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.

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 funding

Radiation, health and environment

Publications

1 Articles in international journals

(with direct contribution from the team)

- *"ALPHACAL: A new user-friendly tool for the calibration of alpha-particle sources"*, A. Fernández Timón, M. Jurado Vargas, P. Álvarez Gallardo, J. Sánchez-Oro, L. Peralta, Applied Radiation and Isotopes 135 (2018) 78–82

Presentations

1 Presentations in national conferences

- Luis Peralta: *"Oficina de formação "Experiências com Arduino: sensores de passagem" "*, 2018-08-29, Física 2018 - 21ª Conferência Nacional de Física e 28º Encontro Ibérico para o Ensino da Física, Universidade Beira Interior, Covilhã

2 Outreach Events

- *"14ª Edição das Masterclasses em Física de Partículas – Hands on Particle Physics, Covilhã"*, 2018-03-17 / 9999-12-31, Covilhã
- *"14ª Edição das Masterclasses em Física de Partículas – Hands on Particle Physics, FCUL"*, 2018-03-17 / 2018-03-17, FCUL, Lisboa

1 Oral presentations in international meetings

- Sandra Soares: *"Assessment of Radon in air and in water in the Portuguese-speaking African countries (PALOP)"*, 2018-05-29, CHERNE 2018 - 14th Workshop on European Collaboration in Higher Education on Radiological and Nuclear Engineering and Radiation Protection Macugnaga (VB), Italy

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)

Organized Events

1 Conferences

- *"Física 2018 - 21ª Conferência Nacional de Física e 28º Encontro Ibérico para o Ensino da Física"*, 2018-08-29 / 2018-09-01, Universidade Beira Interior, Covilhã

1 Workshops

- *"Encontro Radão em Portugal"*, 2018-07-16 / 2018-07-16, LIP, Lisboa

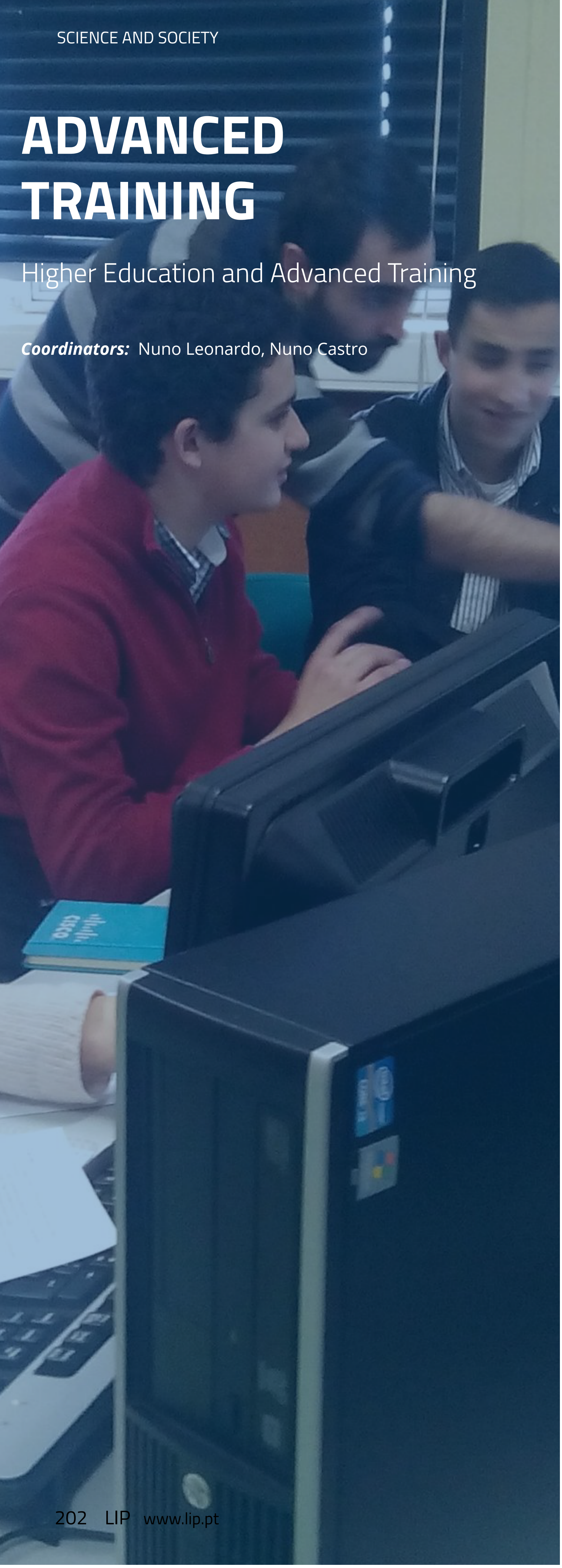
2 Outreach Events

- 14ª Edição das Masterclasses em Física de Partículas – Hands on Particle Physics, Covilhã, Covilhã, 2018-03-17 to 9999-12-31
- 14ª Edição das Masterclasses em Física de Partículas – Hands on Particle Physics, FCUL, FCUL, Lisboa, 2018-03-17 to 2018-03-17

ADVANCED TRAINING

Higher Education and Advanced Training

Coordinators: Nuno Leonardo, 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). Its goals are:

- **Engage undergraduate students**: attract university students to learn about high-energy 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's activities

In 2018, a wide set of activities for undergraduate and graduate students was carried on, and are briefly described below.

Undergraduate students

LIP Summer Internships Programme: In 2018, the programme had its second edition, and is now already a well-established, flagship event of LIP. For the first time, it involved all three nodes of LIP, in a total of over 60 students. 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. The summer programme book of abstracts was published as part of the following edition of the LIP Bulletin (issue 15). The programme counted on a broad participation of LIP researchers, who served as project supervisors, delivered tutorials and lectures, attended and contributed to discussion of results at the final workshop. Besides de inclusion of all LIP nodes, there were other new features in the programme with respect to the previous year, resulting from the analysis of the results of the programme evaluation by students and supervisors. An important novelty was the organization, at the main target universities, of sessions in which the different work proposals were presented, organized by research areas. Again this year, an online anonymous survey was conducted among students. The results were globally very positive and will be taken into account in the organization of next year's edition. As a follow up of the evaluation, a survey is ongoing to understand whether students in the programme keep a connection to LIP after the internship. Preliminary results identified one PhD student and seven master students who enrolled in thesis research at LIP after participating in the internship. In addition, several students kept the connection to LIP to complete a specific goal of 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 udergraduate course. While no causality link can be established at the moment, the number of students in close contact with the groups or deciding to start graduate studies at LIP seems to increase with respect to last years.

Schools & workshops: LIP is involved in several regular school and workshop series directed at undergraduate students, which include lectures, hands-on exercises, and overviews of ongoing research activity at LIP.

- In 2018, the 3rd edition of the Lisbon mini-school in particle and astroparticle physics, co-organized by LIP and CFTP, was held in Oeiras in February and gathered about 20 undergraduate students.
- The 2018 Particles and Light hands-on workshop, held in July at FCUL and IST, counted with the participation of 6 students.
- A new event was the Data Science school and symposium, held at LIP-Lisboa in March. The event had the double goal of providing advanced training and establishing and consolidating the links with other institutions and particularly with the non-academic sector in this field. This is meant to become a regular event series, and will be held again at LIP-Minho in March 2019.

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 (LIP-ROC@IST) was inaugurated in 2017. During 2018, Auger control shifts and, for the first time, CMS monitoring and data quality shifts took place. The CMS shits were effectively used to train the students in the group, but also as opportunities to keep contact with the summer internship students and involve a wider group in the real monitoring procedures of an LHC experiment. The room is meant to be also 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. Furthermore, LIP regularly participates in events organized by physics student associations at the different universities, namely the “Inside Views” of research laboratories during the Physics Engineering Days at IST. In the framework of the MVA4NewPhysics International Training Network meeting in Lisbon, a public session on artificial intelligence and Higgs searches was held at the National Library, gathering over 200 people.

Graduate students

This section concerns the actions directed towards the PhD and master students working at LIP, and also in the framework of international PhD programmes. During 2018, LIP hosted over 50 graduate students. Furthermore, LIP coordinates two 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 Iinternational Training Network, and hosts a PhD student in this context.

The following events and activities took place in 2018:

8th IDPASC international School: held in Valencia, Spain, on 21–30 May 2018, the school included lectures, discussion sessions and a final exam. Over 20 students participated.

4th IDPASC PhD Students Workshop: for two days, all students presented the status of their work to an audience of graduate students and researchers, in Coimbra (28 – 29 June 2018). Keynote lectures on selected topics were also part of the program, including transferable skill lectures on subjects suggested by the students themselves. This year, artificial intelligence, gender issues and space technologies were part of the program.

1st 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. Tuturials and a data challenge were held. Around 40 students participated. 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 May. The course has a final evaluation and now gives credits to PhD students at IST. In 2018, 7 students made a final presentation on a chosen topic.

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 integrations, 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 volunteering basis) and invited to participate in a public session for schools host by the students themselves. In 2018, this session was part of the celebration of LIP's anniversary.

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", in 2018 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 defined by FCT), helps disseminate the calls, particularly through our networks and partner universities and participates in the selection process of the candidates. The process following the 2017 call was quite delayed and only 4 candidates signed the contract to work at CERN within this programme. LIP helped to accelerate the preparation of the 2018 call, which was launched in October, allowing the selection process to start still in 2018. At the end of 2018, a 1-day Workshop was held at CERN, in which the trainees presented their work. A very positive feedback from their 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 2019 is 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, promoting integration and soft skill training. In particular, the path of involving students with LIP and with ECO activities will be pursued. One simple idea is to give visibility to the academic work (performed by the students at the Universities) about the research work they are developing at LIP. A good example is the pre-thesis course master students follow at IST, in which they produce a video (5 minutes long) on the research work they are initiating. These videos are normally shared on YouTube, and we are starting to disseminate them in LIP's website and social media.

Some of the foreseen key initiatives for 2019 are listed below:

LIP Summer Student programme: to pursue this integrated LIP programme is a priority for 2019, building on the experience acquired in the previous years to further improve the programme.

Schools & workshops for undergraduates: namely with the 4th Lisbon Mini School on Particle and Astroparticle Physics, organized by LIP and CFTP in February in Costa da Caparica; the Data Science School and Workshop, held in Braga 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.

Graduate students: among the already foreseen initiatives are:

- Joint IDPASC and LIP student workshop, Braga, July 2019.
- 2019 IDPASC international school: will be held in Otranto, Italy, in May, and will this year be organized in collaboration with the Universities of Bari, Salento, GSSI and the INFN sections of Bari and Lecce.
- The LHC physics course.
- Plus a series of regular seminars and tutorials.

As announced in the last meeting of LIP's scientific council in 2018, LIP students will promote the informal organization of a "LIP Students Council", with the objectives of fostering communication and interaction among student at LIP, for example for choosing representatives, identifying problems or proposals to be brought to the directorate or the scientific council, managing mailing lists and other media for communication (such as the already existing student slack group), sharing tools and information, etc.

Following the path started last year, students will be invited to engage of LIP’s activities for schools, undergoing formal and practical training on public speaking. Sessions for schools with this format are already foreseen for the International Day of Women and Girls in Science (11 February) and LIP’s anniversary (9 May). Other possible occasions are the European Researcher’s Night and the National Science and Technology week (in November).

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 many 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 event organization.

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. Opening positions at universities may strengthen their links with LIP.

Threats

The risk that the multiplication of the activities, together with the lack of manpower, result in poorly organized events that damage LIP’s reputation.

References

LIP summer internship book of abstracts, LIP News Bulletin, pp.24-28, http://www.lip.pt/outreach/lipnews/pdfs/issue15_pt.pdf

LIP summer internship public page, http://www.lip.pt/training/summer-student-program

LIP summer internship, final workshop 2018, https://indico.lip.pt/event/476

ECO

Education, Communication and Outreach

Coordinator(s): Catarina Espírito Santo, Pedro Abreu

Team:
Carlos Manuel, Conceição Abreu, Filipe Veloso, Francisco Neves, Helmut Wolters, Henrique Carvalho, Hugo Gomes, Nuno Castro, Nuno Leonardo, Ricardo Gonçalo, Sofia Andringa

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 an 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 on at LIP. Priority target audiences were defined: our peers (universities, research centres and funding agencies); the LIP community; undergraduate students in Physics and Engineering; the school community. The activities of LIP-ECO involve all three LIP nodes. Furthermore, they are transversal activities, which depend upon the collaboration of all the groups.

At national level, we are partners of Agência Ciência Viva, the Portuguese Physics Society, and have a close collaboration with several schools. LIP is part of the International Particle Physics Outreach Group, European Particle Physics Communication Network and the CERN forum for high-school students and teacher programmes. During the last year, we highlight our participation in the preparation of the documents sent by EPPCN and IPPOG as inputs to the ongoing update of the European Strategy for Particle Physics.

In 2018, we select as highlight of the year the project "SciCom with and for Students", with the goal of involving LIP's PhD and master students in outreach activities. This project gets the younger members of the different groups to work together, promoting communication and team spirit. From the education and outreach point of view, the received feedback indicates that young people can be very effective in communicating to school students. From the advanced training point of view, this project contributes to give students useful soft skills training. as public speaking training is offered to the participants.

ECO

Last year's activities

1. Communications

External communications

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. Two issues of the LIP-News Bulletin were released in 2018. An effort was put in increasing quality, including in particular: (i) a stronger editorial plan, with a more careful selection of covered topics; (ii) the contribution of a wider group of authors, both from the LIP research groups and invited authors; (iii) only two issues published per year, allowing for issues with longer preparation times and thus more pages and a more careful graphical work.

LIP web site: The new LIP web site (released in 2016/2017) continued to be developed and upgraded. Important aspects in 2018 were: (i) A more dynamic set of news items and agenda of events in the main page; (ii) improvement of the "Science and Society" area of the site, in particular with information about new projects with schools, information for the media and list of outreach seminars proposed to schools by LIP researchers. The site is equipped with the tools to perform visitor statistics and the analysis work has just started.

Social networks: LIP is present in the social networks Facebook, Twitter and linkedin, and a member of the team has some time specifically allocated to this task. In 2018, the focus was put in consolidating the presence in twitter and in promoting a stronger participation of the LIP research groups to the social media. This goal has, to some extent, been achieved, although there are at present strong asymmetries between the different groups. 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.

Press/media: Although this is not chosen as a priority, a number of press releases have been issued and some nice successes attained — in particular the publication in Público, a reference national daily newspaper, of articles related to LIP's research and based on our press releases. A good example is the observation of the Higgs boson decay to bottom quarks [1] and of the Higgs boson production with a top quark [2]. The LIP group in ATLAS works in both these analyses. Another example are recent multi-messenger astronomy results, published by collaborations in which LIP is not directly involved, but clearly related to our area of research, and to our present and future projects, namely Auger and LATTES [3].

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. In 2018, the flyer introducing LIP has been totally re-done. The design work for producing some limited merchandising (mainly pens and notebooks), and also a roll-up, has been performed. The goal is to improve the way in which we present LIP, in order to foster the impact of our communication. We are nevertheless behind schedule, mainly due to lack of manpower.

LIP yearly reports and plans: LIP-ECO is responsible for the edition of LIP's yearly reports and plans. Since 2015, two different reports are prepared. The detailed activity report and plan is meant to give a complete, in detail 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.

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, is still ongoing. In 2018, LIP-ECO provided support to the preparation of the visit of the LIP premises of the evaluation panel. This visit is expected in mid 2019.

SciCom academic work and conferences: The construction of LIP-ECO was the subject of a master thesis on Science Communications delivered and discussed in 2018 [4]. At the national science communication conference SciCom.pt the co-coordinator of LIP-ECO was part of a discussion panel on the origin of hype in science news.

Internal communications

Following the survey on the status and tools of internal communications conducted in 2017, several steps have been taken in 2018:

cLIP digital newsletter: A digital internal newsletter was created under the motto "Widening participation for better communications at LIP" and issued monthly starting in March 2018. The newsletter is meant to convey organizational information to LIP members, both external (call, evaluations, etc.) and internal (organized events, administrative procedures and deadlines) as well as information on scientific highlights and on the work of the different groups, improving the sharing of information between the different groups and across the three LIP nodes, as well as the participation of the groups in ECO activities.

LIP intranet: The new LIP intranet was released in 2018 and now plays a crucial role in internal communications. Important aspects are: (i) more complete practical information and information for newcomers; (ii) easier access to documentation, such as regulations, reports, etc; (iii) a more complete agenda of events of interest for LIP collaborators. In 2019, important work on user authentication will be performed by the Computing Group, which will improve accessibility and security in the LIP web domains.

Event organization and event registration form: Support to event organization involves secretariat, computing and ECO services. In the last couple of years, the large number of events organized or supported by LIP (conferences, collaboration meetings, schools, workshops, public sessions) made it difficult for these services to adequately plan the work, in particular due to many last minute and/or unrealistic requests. For these reasons, an online event registration form was created and must be filled well in advance by the organizers of the event. In this framework, LIP-ECO gave support in handling the web pages and advertising a large number of events, both in the LIP channels and through our links to the universities communication offices, research labs, physics student organizations and schools.

Science Communication training: for the second consecutive year, a one-day workshop on speaking in public with a recognized expert in the field was offered to the LIP community. This year, we encouraged in particular PhD and master students to participate. Eight people attended the workshop, and the results of the satisfaction survey were very positive.

Fostering the participation of the LIP groups in ECO activities: An effort was made to make participation easier (through pre-prepared online shared forms and files, for example) and the role of group's contact person for communication, which existed already in each group, was revitalized. Along the year, we noticed a clear increase in the number of suggestions for site news and social media posts, although there is still a large asymmetry between the different groups. In the final part of the year, regular LIP-ECO meetings open to the ECO contacts in the groups have been started. The "2018 Highlights" campaign on facebook showed a good level of participation.

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 start of new projects, concerning mostly collaborations with schools along the year on more hands-on projects.

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. In addition, a study on gender balance among Masterclass participants has been initiated, using data from different sites and evolution with time.

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 20 students to learn about experimental particle physics and directly experience the work of scientists in the field. Within the internship's progamme 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 12th edition of the school was held in the beginning of September, attended by 20 Portuguese teachers and 20 Brazilian teachers. In this edition, it was again not possible to obtain support to bring 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 650 teachers have attended the school, which is considered one of the best teacher training programmes at CERN.

Seminars in schools: More than 50 outreach talks were given by LIP scientists in schools, mainly in the areas of Braga, Coimbra and Lisboa but also occasionally in other places. A new fact in 2018 was the creation of a list of talks proposed to schools, which is available on the outreach section of the LIP web site. The goal is to diversify the subjects and speakers that actually go to schools, and also to bring more schools into the loop.

Special outreach events: A couple of special outreach moments are highlighted below:

- **LIP's anniversary** was celebrated inviting secondary school students and teachers to a public session presented by PhD and master students from LIP, with the title "LIP: from the depths of the Earth to Space — a tour around the world in 80 minutes (or less)". We had more than 70 participants (the number of chairs in the auditorium) and very positive feedback from students and teachers.
- The school "How to become an astronaut" at the Astronomical observatory of the University of Coimbra, co-organized by LIP, school hosted about 40 students during four days.
- In 2018, LIP was at the **European Researchers Night** in Braga, Coimbra and Lisboa. At Forum Braga, visitors built detectors and searched for particles in the city. At the Science Museum of the Univeristy of Coimbra, there was time to see cosmic rays and to learn about how positron emission tomography works. In Lisbon, we travelled to CERN with a virtual visit to the CMS experiment and the movie "Particle Fever".
  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. Two models are to be developed in parallel: longer-term projects developed along the year with students and teachers, in the LIP-EduLab and in the school; and short workshops and visits to LIP, combining introductory talks and hands-on sessions. The LIP-EduLab, created at the new LIP-Lisboa premises in 2018, is the formal start of the project of building at LIP a teaching laboratory devoted to particle physics and its tools. Particle detectors, data acquisition, sensors, raspberry pi, simple python programming exercises, data analysis and, in general, the methodologies and tools of experimental physics are the aspects to be addressed. In 2018, the LIP-EduLab initiated a pilot phase, and was tested first in 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. For the moment, the available material is very limited, and based on existing kits (for example, small cosmic muon detectors, built in summer internships or projects with schools, or ordered to CERN). 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. Overall, the pace of the LIP-EduLab development will depend on the available resources, both human and financial.

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: A. Blanco, L. Lopes), and for which there are several pending orders from national and international institutions. The main developments in 2018 include improvements in the cloud chamber developed at LIP-Coimbra in 2017 (coordination: F. Neves, see Dark Matter Group report for details). On the other hand, the use of RPC-based detectors for educational purposes is being pushed forward (coordinator: L. Lopes).

Concerning the specific competences existing at LIP-Minho (multimedia, virtual reality, etc.), the work is progressing but, again, at a slow pace due to other commitments. A powerful 3D event display of the Pierre Auger Observatory has been developed and used for demonstrations in outreach events. It will also be used for visualization and analysis of the Auger public data, available for educational purposes. It is worth mentioning that H. Carvalho participated in LHCreate, a two-day workshop at CERN, to design exhibits about physics, and his team actually won the competition.

Other activities: LIP gave logistic support to Portuguese schools organizing visits to CERN or participating in the CERN Beamline for Schools competition.

Prospects for next year

In 2019, the consolidation of the activities and services already provided to the LIP community and to the public remains a priority, as many new tasks and projects have recently been initiated, and human and material resources are 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. Dedicated efforts to reinforce the available resources must be pursued. This means 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.

1. Communications

In 2019, the organization work in the wide set of tasks concerning institutional communications will be pursued, progressively widening the addressed challenges and thus the responsibilities. In what concerns internal communications, the main goals are to foster the participation of the research groups (in all three nodes of LIP) in ECO and to change the communication patterns of those who are not yet users of the new communication channels (in particular the cLIP digital newsletter). Making useful information and material (e.g. templates, images, calendars, etc.) available in these channels is certainly a good strategy. Another one is to directly involve graduate students, who are usually open both to ECO and to new communication channels, and are then able to influence the group they work in.

Externally, the main goal 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 key publics in key moments during 2019? What are the relevant messages and the adequate channels to spread them? The choices made are summarized in the table below. They are centered on projects that involve reaching out for other institutions and sectors, or applications particularly prompt to public visibility. Another area in which we will progress in 2019 in the preparation of promotion material: a video introducing LIP (the first of a set of videos in the several research areas); and simple merchandising. This has been pending for a couple of years already, due to lack of resources, but becomes increasingly important as the initial organization work progresses and we start to be able to turn more to the outside.

2. Education and outreach

In 2019, we expect the 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. 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 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. At present, there are several emerging projects for the collaboration between schools and research institutions, proposed by the Ministry of Education and by Agência Ciência Viva. LIP has expressed the interested to participate, established partnerships with several schools, and started activities. It is now important to better define the framework for these collaborations, namely in what concerns its goals, practical implementation and funding. Also here, 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 be developed under the motto “particle physics and its tools” and we foresee two usage models:

- Workshops: preparing a number of workshops, which can be offered to high-school students and teachers coming to LIP for short visits, summer internships (such as the Ciência Viva no Laboratório internships, which will again be a good test bench for the lab), or collaborations with schools along the year.
- Support: creating a structure able to give support to projects developed in the schools. On one side, basic tools and some technical support; on the other side, an effort to make some of the workshops “portable”, so that they can be held in schools.

This requires the acquisition of a small set of material, and also the reinforcement of the team collaborating in the lab. This 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. Recently a first prototype of its RPC-based detector has been installed at the Lousal mine, now a science center in southern Portugal. The project has great outreach potential, and already foreseen are: the preparation of printed and online information material; a set of seminars at Lousal followed by visits to the mine; the development of a module on the project for the local science exhibition.

Topic	Key events/aspects	Communication guidelines
LHC	• MoU signature • Fundo CERN • Upgrade HL-LHC/PT industry • EPPS upgrade	• Regular appearance in the media and LIP channels: run 2 results, PT industry, Granada meeting • VIP Event: LIP's anniversary / MoU • Universities: training opportunities, engineers at CERN programme
Data Science	• Competence centre, inter-group activities • Projects with other institutions • European Projects	• Workshop/school in Braga is main event and should be adequately covered • Cover of next Bulletin • Visibility to partnership projects, when advanced enough
Space applications	• H2020 project: Moon radiation environment and solar events • PT R&I Agenda for Space and Earth Observation	• Press release when/if approved? • Regular appearence in LIP channels • Highlight for the next issue of SPF magazine, "Gazeta da Física"?
Health Proton-therapy (p-T) Radon	• Collaboration with CTN and ICNAS • p-T: Commission report and political evolution • Radon: EU directive, national radon map,LapExpoRad certification	• Highlights at the next Bulletin (and site news): Projects with CTN and ICNAS, interview on the directive and map (J. Sampaio); interview on lab certification (S. Soares). Interest from UC too.
Computing	• Infrastructures (INCD, Iberian grid) • European projects	• Regular visibility in LIP channels (and media?) • Coordination with INCD is crucial
Astroparticles Muon tomography (MuTom) LATTES Neutrinos	• Links to society/applications • Gamma-ray meeting in PT can be an important moment for the community • Multi-messenger astronomy • New flagship projects at LIP	• MuTom demonstrator installed in the Lousal mine: follow up in LIP channels, and specific outreach programme • Regular coverage of LIP's participation in large experiments; follow international press releases; prepare or adapt multimedia support materials (in particular, focused on LIP's involvement)

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

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. 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.

References

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[4] C. Espírito Santo, ”A construção do Gabinete de Comunicação do LIP: da estratégia aos resultados”, FCSH, Universidade Nova de Lisboa

[5] H. Fernandes, M. Abreu, ”The World Pendulum @ São Tomé”, Europhysics News vol.49, nº 2 pg.6, March-April 2018

Summary Tables

Funding

Human Resources

Scientific Output

FUNDING

Group	Code	Amount	Entity	Dates	LIP node
ATLAS	IF/00955/2013/CP1172/CT0004	50.000 €		2013-12-01 / 2018-11-30	
"	IF/00050/2013/CP1172/CT0002	50.000 €		2014-01-01 / 2018-08-31	
"	IF/01586/2014/CP1248/CT0003	42.000 €		2015-01-01 / 2019-12-31	
"	CERN/FIS-PAR/0008/2017	340.000 €		2017-07-01 / 2019-06-30	
CMS	IF/01454/2013/CP1172/CT0003	50.000 €		2014-01-01 / 2018-12-31	
"	IF/00772/2014/CP1248/CT0002	50.000 €		2015-01-01 / 2019-12-31	
"	AMVA4NewPhysics - 675440	238.356 €		2015-09-01 / 2019-08-31	
"	CERN/FIS-PAR/0006/2017	345.000 €		2017-08-01 / 2019-07-31	
Pheno	CERN/FIS-PAR/0015/2017	10.000 €		2017-11-01 / 2019-10-31	
"	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	
COMPASS	CERN/FIS-PAR/0007/2017	165.000 €		2017-09-01 / 2019-08-31	
NUC-RIA	CERN/FIS-PAR/0005/2017	24.640 €		2018-07-01 / 2020-02-29	
AMS	CERN/FIS-PAR/0020/2017	35.000 €		2017-09-01 / 2019-09-01	
Auger	IF/00820/2014/CP1248/CT0001	50.000 €		2015-01-01 / 2019-12-31	
"	FAPESP/19946/2014	200.000 €		2015-09-01 / 2018-08-31	
"	CERN/FIS-PAR/0023/2017	150.000 €		2017-05-02 / 2019-05-01	
LATTES	PTDC/FIS-PAR/29158/2017	239.885 €		2018-05-15 / 2021-05-14	
Dark Matter	PTDC/FIS-NUC/1525/2014	199.280 €		2016-01-01 / 2018-08-31	
"	PTDC/FIS-PAR/28567/2017	239.807 €		2018-09-01 / 2021-08-31	
SNO+	IF/00863/2013/CP1172/CT0006	50.000 €		2014-01-01 / 2018-12-31	
"	PTDC/FIS-NUC/0640/2014	184.276 €		2016-02-01 / 2018-10-31	
SHiP	CERN/FIS-PAR/0030/2017	10.000 €		2018-01-01 / 2019-12-31	

Group	Code	Amount	Entity	Dates	LIP node
Neutron Detectors	654000 SINE2020	153.750 €		2015-10-01 / 2019-09-30	
Gaseous Detectors R&D	PTDC/FIS-NUC/2525/2014	60.000 €		2016-05-01 / 2018-05-31	
"	CERN/FIS-INS/0025/2017 - GD	35.000 €		2018-05-01 / 2020-04-30	
Liquid Xenon R&D	CERN/FIS-INS/0025/2017 - LXe	35.000 €		2018-05-01 / 2020-04-30	
Gamma Cameras	IF/00378/2013/CP1172/CT001	50.000 €		2014-01-01 / 2018-12-31	
Space Rad	ESA: 1-7560/13/NL/HB	300.000 €		2014-02-18 / 2020-06-30	
"	ESA: 3-14025/13/NL/AK	60.000 €		2014-03-17 / 2018-12-31	
"	ESA/4000115004/15/NL/RA/ZK	80.116 €		2015-11-13 / 2019-12-31	
i-Astro	654215 - AHEAD	61.225 €		2015-09-02 / 2019-02-28	
GRID	INCD 01/SAICT/2016 - nº 022153	223.000 €		2017-07-18 / 2019-12-31	
"	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	
Simulation & Big Data	PTDC/FIS-PAR/29147/2017	239.988 €		2018-07-01 / 2021-06-30	
ECO	EPPCN - KE2826	23.500 €		2016-01-01 / 2020-12-31	
"	92-2018/841 Masterclasses	2.500 €		2019-02-15 / 2019-08-31	

Human Resources on research (2018)

Group	FTE	Heads(*)	Researchers	Technicians	PhD	Master	Underg+Train	External
ATLAS	22.8	39	18	3	7	11	8	7
CMS	18.3	24	11	2	6	5	14	4
Pheno	9.0	20	10		3	7	1	4
COMPASS	4.6	5	4	1			6	1
HADES	0.5	6	4	2				
NUC-RIA	3.1	6	1		3	2	4	1
AMS	3.3	5	4		1		4	2
Auger	13.5	27	17	7	1	2	5	2
LATTES	3.0	15	12	3			5	4
Dark Matter	9.6	17	10	2	2	3		
SNO+/DUNE	6.2	11	7	1	2	1	6	2
SHiP	2.0	9	3	6				
RPC R&D	3.5	9	6	2	1			
Neutron Detectors	1.3	4	4					1
Gaseous Detectors R&D	4.5	9	6		2	1		
Liquid Xenon R&D	1.0	4	4					
OR Imaging	1.6	2	2					
Gamma Cameras	2.8	9	6	2	1			
Dosimetry	2.5	7	3		1	3		
Space Rad	5.7	10	6		2	2	7	2

Human Resources on research (2018)

Group	FTE	Heads(*)	Researchers	Technicians	PhD	Master	Underg+Train	External
i-Astro	4.6	12	6	1	4	1		
GRID	11.0	13	6	7				5
Advanced Computing	3.0	3	1			2		3
Radiation, health and environment	5.7	11	5		3	3		2
total	150.1	277	99	28	34	40	62	45

Scientific output

Group	Jrn-I	Jrn-II	Other	Int.o	Int.p	Nat.	Int.meet.	Seminars	Outreach	D	M	Events
ATLAS	103	11	16	6	4	19	4	10	18		4	1
CMS	145	7	14	13	1	5	4	20	5		1	
Pheno		10	4	8	1	1	5	4			1	
COMPASS		8	4	4		2		1				
HADES	3			1		1	1					
NUC-RIA	4	1										
AMS	3	2	2	1	1	2		2	2			
Auger	4	4	3	5	1	11	7	3	5		1	
LATTES	3	1	1	2		2	4	2	2			2
Dark Matter	3	3	3	8	1	4	1	3	1			
SNO+	2		7	3	2	1		1				
SHiP	2											
RPC R&D		1		1		1	1					
Neutron Detectors		1		4		1						
Gaseous Detectors R&D	8									1		
Liquid Xenon R&D												
OR Imaging		2	1	2		4	1	1		1		
Gamma Cameras				1		2						
Dosimetry	1	8				1						2
Space Rad		4	4	2	2	11		2	7			

Scientific output

Group	Jrn-I	Jrn-II	Other	Int.o	Int.p	Nat.	Int.meet.	Seminars	Outreach	D	M	Events
i-Astro	1	4	3		2	2			5		1	3
GRID		4	5	3		5	6	2				2
Advanced Computing												
Radiation, health and environment		1				1	1		2			4
TagusLIP		2								1		
Sim. and Big Data	1	1										
TOTAL	**283**	**69**	**66**	**64**	**15**	**75**	**35**	**50**	**43**	**3**	**8**	**16**

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
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