# ANNUAL REPORT

## 2018/2019

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
*partículas e tecnologia*

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# ABOUT LIP

# LIP is the reference laboratory for experimental particle physics and associated technologies in Portugal

LIP exists for the discovery of the fundamental laws of the Universe, ensuring the full participation of the Portuguese scientific community in this endeavour, and to share this knowledge with society. The laboratory is nation-wide, with nodes in Lisboa, Coimbra and Braga, working in close collaboration with the local universities. It has close to 200 members, including over 80 PhD researchers and 70 graduate students.


Under the supervision of FCT, LIP defines the national research agenda for experimental particle physics and the Portuguese participation at CERN and in other international scientific infrastructures. LIP is the Portuguese reference partner of CERN, and also a partner of ESA, the GSI research centre in Germany, SNOLAB in Canada, the Pierre Auger Observatory in Argentina and the Sanford Underground Research Facility (SURF) in the USA. The associates of LIP are FCT, the Universities of Lisboa, Coimbra and Minho, Instituto Superior Técnico (IST), the Faculty of Science of the University of Lisbon (FCUL) and the Electrical and Electronics Business Association.

**The three pillars of activity at LIP are:**

- **Discovery through science:** LIP's program of experimental particle and astroparticle physics is international, has world-class quality and addresses some of the most topical questions of our time.

- **Innovation through technology:** basic science drives innovation in the long term. LIP is a key player in the application of particle physics technologies to health care and space exploration, and in scientific computing.

- **Sharing with people:** LIP works to engage society in science, to inspire the younger generations to pursue careers in science and technology, and to address societal challenges through science.

**LIP is committed to R&D in three main areas:**

- **Experimental particle and astroparticle physics;**

- **Development of new instruments and methods;**

- **Scientific computing.**

LIP is deeply involved in the CERN Large Hadron Collider (LHC) programme, contributing from the very beginning to the two largest LHC experiments, ATLAS and CMS, and exploring new physics phenomenology. LIP is also involved in the fixed target programmes at CERN and GSI, probing the strong nuclear force and dense nuclear matter. The quest for dark matter, a deeper understanding of the elusive neutrinos, or the study of hadronic interactions at the highest energies in cosmic rays are among the great challenges of particle physics for the next decades, and part of our agenda.

The development of new instruments and methods for particle physics has been from its inception one of the main strengths of LIP. Current activities include research in fundamental detection processes and applications of particle detectors. LIP is a world leader in Resistive Plate Chambers (RPC) and liquid xenon detectors, with

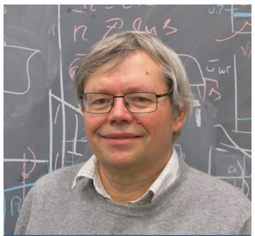
strong expertise in other gaseous detectors, scintillator/fibres calorimetry, and fast electronics for data acquisition systems. Specific R&D lines are dedicated to health care and space exploration applications.

LIP develops novel information technologies and operates advanced services to support demanding scientific applications, focusing on Grid and Cloud computing technologies. LIP participates in some of the largest R&D projects in this field, operates the largest scientific computing facility in Portugal, and delivers services to the scientific community at large. LIP co-leads the National Distributed Computing Infrastructure.

**Our vision for the future** is to make sure that LIP will be present in the next great scientific discoveries of humankind, and lead science and innovation in Portugal in close connection with the academic and business communities.

DIRECTORATE'S REPORT

# Preparing the future



prof.
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 ultrahigh 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-of-view 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 $^{3}$He-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 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 has been, and will be deeply involved in international service and research projects, both at Iberian and European level.

**LIP's 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 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 clear: 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 centres**, 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 centres 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.

## DIRECTORATE'S REPORT

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 suffcient, 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.

(Mário Pimenta)

# Report from the International Advisory Committee

The LIP International Advisory Committee met in Coimbra on 3rd and 4th May 2019. Prior to the meeting, the Committee had received extensive and well-prepared documentation about the LIP activities. Oral presentations and discussions during the meeting provided further relevant information.

LIP's primary mission is the study of the fundamental laws of particle physics. The accelerator-based programme of this research is carried out at CERN, principally with the two flagship experiments ATLAS and CMS at the LHC. Cosmic rays and their astrophysics implications are studied with the world's largest array of earth-based detectors (Auger in Argentina) and on the International Space Station (AMS). Search for Dark Matter in our Universe is pursued with the LUX-ZEPLIN (LZ) experiment (in USA) and neutrino properties are investigated with SNO+ in Canada. These research programmes are conducted in large international scientific collaborations in which LIP has many leading positions, shares major responsibilities and makes first-class scientific contributions.

In parallel, LIP prepares for the future. In 2018, LIP teams continued to make significant progress with R&D and design towards the upgrade of ATLAS and CMS in preparation for the High-Luminosity LHC. The LIP teams also continue to make world-class contributions to the physics research based on LHC data. LIP has joined the DUNE collaboration on neutrino physics as a logic continuation of their SNO+ efforts and has already been entrusted with significant responsibilities. LIP is among the proponents of the new SHIP facility at CERN, proposing its RPC technology for precision time-of-flight measurements, in a programme searching for weakly interacting long-lived particles and studying neutrino physics. Noteworthy and very productive is the close involvement of LIP theorists in the interpretation of the results obtained by the experimental groups.

A second major pillar of LIPS's activities is the development of applications which have a direct and beneficial impact on society. This line profits from the competence of individuals and teams, notably particle detector R&D and construction techniques, electronics and computing. LIP's development of novel medical imaging instrumentation is one promising example. LIP also makes significant contributions to important programs in terrestrial and space radiation simulation and environmental monitoring.

LIP is maintaining its outstanding leadership in scientific computing, both internationally and within Portugal. Software developments, advanced algorithms and techniques and an excellent record of system management, performance and availability have made LIP a most welcome partner in several international projects as well as the leader in the deployment and operation of the Portuguese scientific computing infrastructure. The LIP computing teams are engaged in many important international collaborations and have again remarkably progressed in 2018.

LIP is aware of the importance of communicating science to the Public. Its staff is fully engaged in an innovative outreach programme, with an emphasis on attracting students to STEM and to particle physics, through seminars, masterclasses, internship and summer courses. The Committee considers this activity exceptional at a European level.

As noted previously, the remarkably diverse and multi-faceted research and R&D activities carry a certain risk of fragmentation. The LIP Leadership is fully aware of this risk and during 2018 has continued their efforts in sharpening the focus. As a consequence, several activities will be brought to a logical conclusion during 2019. R&D in the medical field will concentrate on the development of a brain scanner using LIP RPC technology and on another novel imaging technique. These efforts should get a boost in view of the planned construction of a center for tumor therapy with proton beams.

Streamlining of efforts has also taken place in the study of detector properties and performance. All these actions aim at increasing efficiency in the use of the limited resources. The Committee applauds and encourages the LIP Management to pursue these lines of convergence.

The Committee was pleased to learn that the employment conditions at LIP continue to improve with the establishment of several professorships and the award of indefinite contracts. It is essential that these improvements continue, that ways are found to increase the ratio of permanent to fix term contracts to an international level and to provide a career perspective for young researchers. The Committee encourages the LIP management to continue their constructive efforts in this direction.

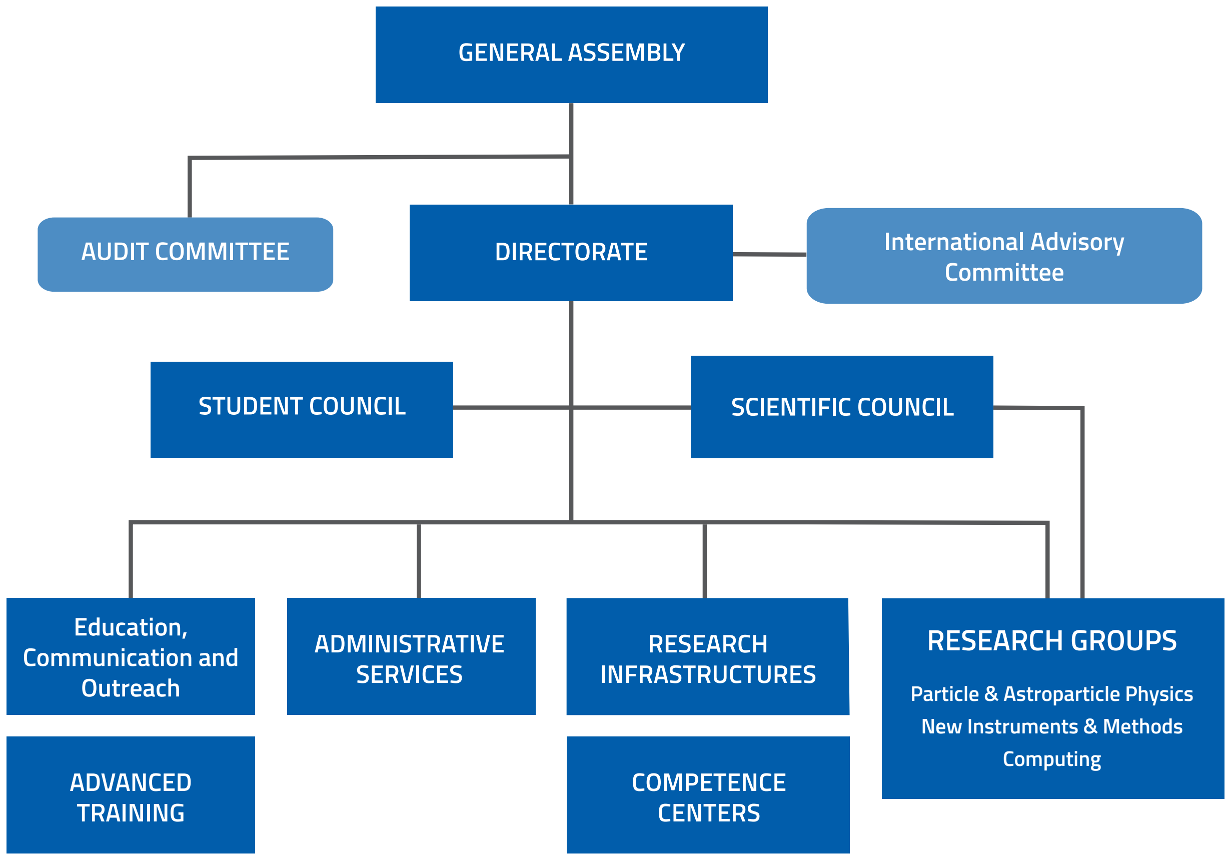
The new management structure established in 2018 has proven to be effective. Notable achievements are the improved coordination among groups active in neighboring fields of research. The recently established Competence Centers is another fine example of improved use of human resources and competence.

LIP employs its limited financial and personnel resources with great care, which is one important factor for its remarkably successful and multi-faceted programme. The Committee is impressed by the scientific output of many research groups, despite sometimes extremely limited resources. Unsurprisingly, these restrictions are clearly limiting a number important of LIP activities.

The Committee feels appropriate to repeat its suggestion that the available funds could be used even more effectively if the Portuguese medium-term funding strategy would be more closely aligned with the long-term scientific research plans and engagements of the Laboratory.

The Committee congratulates the LIP directorate and the LIP staff for another exceptionally productive year with an impressive range of world-class activities. It thanks the Laboratory for the efficient organization of the review and for its hospitality.

# Structure and governance




Research in experimental particle physics and associated technologies is often conducted within large international collaborations or using large scientific infrastructures. This requires research teams large enough to have the required critical mass and adequate support infrastructures. The organizational structure of LIP ensures a coordinated strategy at national level and is designed to be efficient and flexible.

## The governing, supervision and advisory bodies of LIP are the following:

### General Assembly

LIP is an Associated Laboratory of the Ministry of Science, Technology and Higher Education. The associates of LIP are the Portuguese Foundation for Science and Technology (FCT, president), the Universities of Lisbon, Coimbra and Minho, Instituto Superior Técnico (IST), the Faculty of Sciences of the University of Lisbon (FCUL) and ANIMEE (Electrical and Electronics Business Association).

### International Advisory Committee

An External Advisory Committee provides strategic advice to the Laboratory. The Committee is formed by seven worldwide recognized experts in the areas of activity of LIP and holds regular meetings with the directors and the group leaders. Presently, the members of the International Advisory Committee are: Christian W. Fabjan (Austrian Academy of Sciences), Eamonn Daly (former Head of Space Environment and Effects Section of ESA), Katia Parodi (Medical Physics Chair at LMU, Munich), Luigi Rolandi (CERN), Masahiro Teshima (Director of the Max Planck Institute of Physics), Pier Giorgio Innocenti (former CERN ECP Division Leader), Sergio Bertolucci (former Director of Research and Scientific Computing at CERN).

### Audit Committee

LIP administrative and financial operations are systematically audited by external auditors and reviewed by a top level independent finances council and auditing authority. Members are: João Ferreira do Amaral (president), António Morão Dias, Vera Martins.

### Directorate

LIP is governed by a Board of Directors nominated by its General Assembly, after consultation of LIP members. The different nodes of LIP are represented in the Board of Directors, which meets on a monthly basis and issues brief reports of its deliberations to the scientific council. At present the national directorate is formed by Mário Pimenta (president), Isabel Lopes, Nuno Castro, Patrícia Gonçalves and Rui Ferreira Marques.

**Scientific Council**

LIP's Scientific Council is the laboratory's scientific management body. Its members include all PhD holders, a representative of the technical staff and a representative of the students from each LIP node. The Scientific Council participates in the definition of the scientific strategy of the laboratory, namely in the creation of new research groups and in the decision to participate in international collaborations, as well as in the evaluation of LIP's researchers. The Scientific Council delegates some of its authority to a committee where all research groups are represented. Presently, the Scientific Council board is formed by José Maneira (president), Helmut Wolters and Raúl Sarmento.

**Student Council**

The goals of the recently created LIP Student Council are: to promote and enhance communication between students from different LIP nodes; to encourage the exchange of ideas, interests and mutual aid between students, and to promote teamwork; to provide means for student assistance in LIP affairs and activities, and to make sure that new students are well integrated in their new work environment; to suggest and assist in the preparation of advanced training activities relevant to LIP's scientific interests.

## The main elements of the working structure of LIP are:

**Research Areas and Research Groups**

Research Groups are the fundamental organizational units of LIP. The research groups are organized in eight Research Lines gathered in three Research Areas: particle and astroparticle physics; development of new instruments and methods; scientific computing.

**Research Infrastructures**

Research infrastructures are central in the laboratory's activities. They provide support to R&D activities at LIP and services to external entities. The existing infrastructures are: the precision mechanical workshop and the detector laboratory in Coimbra, the scintillating materials laboratory and the electronics laboratories in Lisbon.

**Competence Centres**

The Competence Centres cluster related expertise from the different research groups and infrastructures of LIP to create a pool of knowledge that eases R&D and can provide services to external entities and foster knowledge transfer into the non-academic sector. They are designed to be light and flexible horizontal structures joining all the LIP members that share the same tools and technologies. For the moment, two competence centres have been created: the Simulation and Big Data Competence Centre, and the Monitoring and Control Competence Centre.

**Administrative services**

The LIP community has the support of a small but effective group of administrative staff (five elements in Lisboa and two in Coimbra).

**Advanced training office**

The advanced training office organizes schools, workshops and internships for undergraduate and graduate students; it also oversees the hosting and training condition of PhD and master students at LIP.

**Education, Communications and Outreach office (ECO)**

The LIP-ECO office coordinates the ECO related activities carried out at LIP, including corporate communications (internal and external), outreach and support to education.

# Highlights of the year

January 2018
**New European Strategy for Astroparticle Physics presented**

January 2018
**Third Lisbon Mini-school on Particle and Astroparticle Physics**

February 2018
**Jornadas do LIP**

February 2018
**First high-precision meseaurement of the W mass at the LHC**

March 2018
**1st Symposium+School Data Science in (Astro)Particle physics and the bridge to industry**

March 2018
**Strategic orientation for the creation of a proton therapy unit approved by the Council of Ministers**

March-April 2018
**IPPOG International Masterclasses in Particle Physics in Portugal,**

April 2018
**LUX/LZ collaborations meetings in Coimbra**

May 2018
**SNO+ Control room at LIP is operational**

May 2018
**LIP joins the DUNE Collaboration**

May 2018
**Production of important elements of the MARTA DAQ system completed at the eCRLab**

June 2018
**ttH 5 sigma Observation in CMS and ATLAS**

June 2018
**CMS quality control shifts at LIP control room at IST**

June 2018
**BEACH Conference in Peniche, Portugal**

July 2018
**International Physics Olympics in Portugal**

July-September 2018
**II edition of the LIP Summer Student Programme,**

July 2018
**Multi-messenger astronomy in Science: neutrinos and gammas from the same source**

August 2018
**Higgs decay into a b-quark pair observed by ATLAS and CMS**

August 2018
**Members of the LIP NUC-RIA and HADES groups prepare to the Phase-0 of FAIR at GSI**

September 2018
**Portuguese language teachers programme held at CERN,**

September 2018
**European researchers night in Braga, Coimbra and Lisboa**

October 2018
**Digital Infrastructures for Research 2018 Conference**

October 2018
**IBERGRID 2018 Conference**

October 2018
**Update of the European Strategy for particle physics launched at CERN**

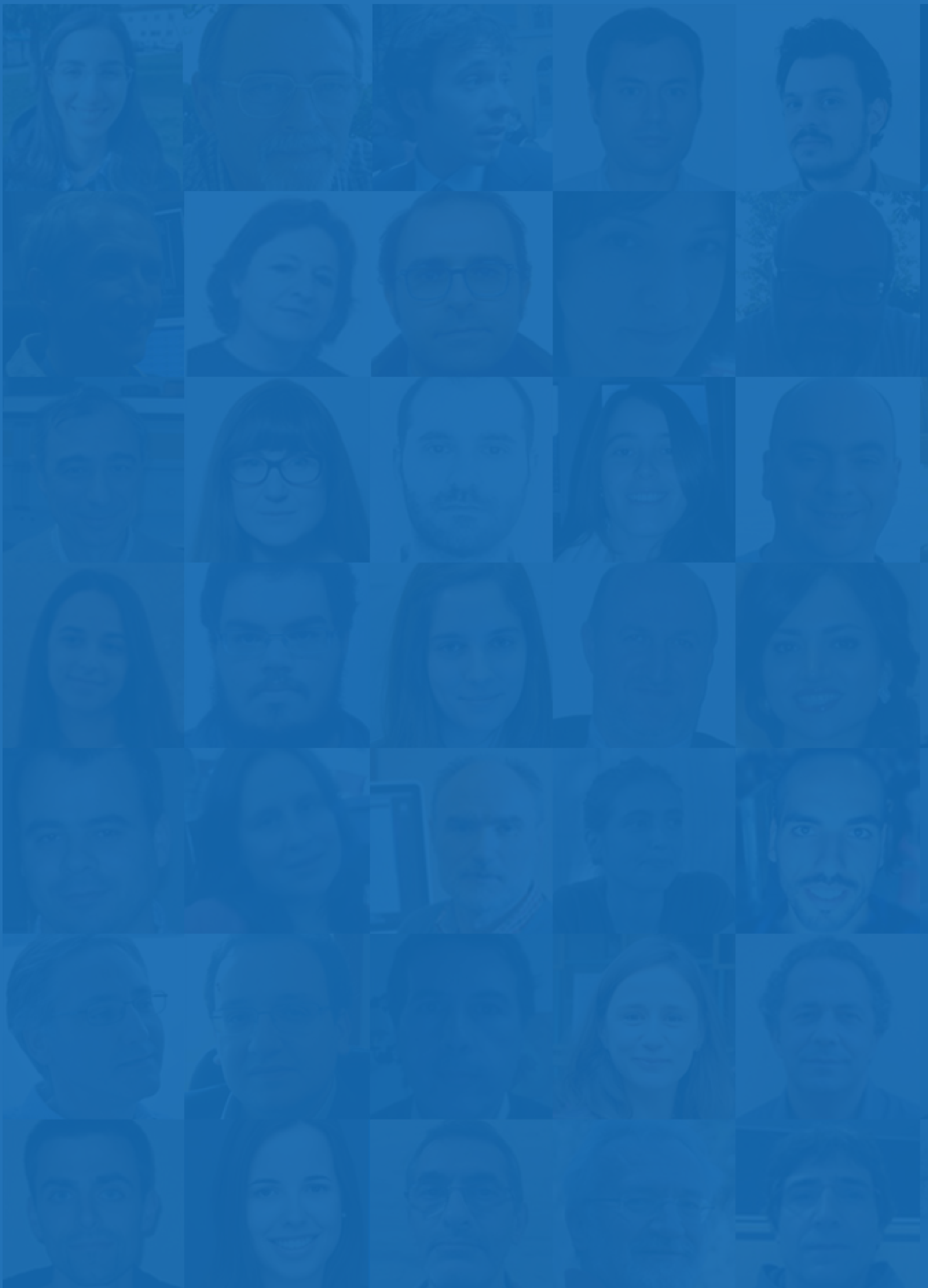
October 2018
**LIP participates in R&D for SHiP with tests of a new detector concept at CERN**

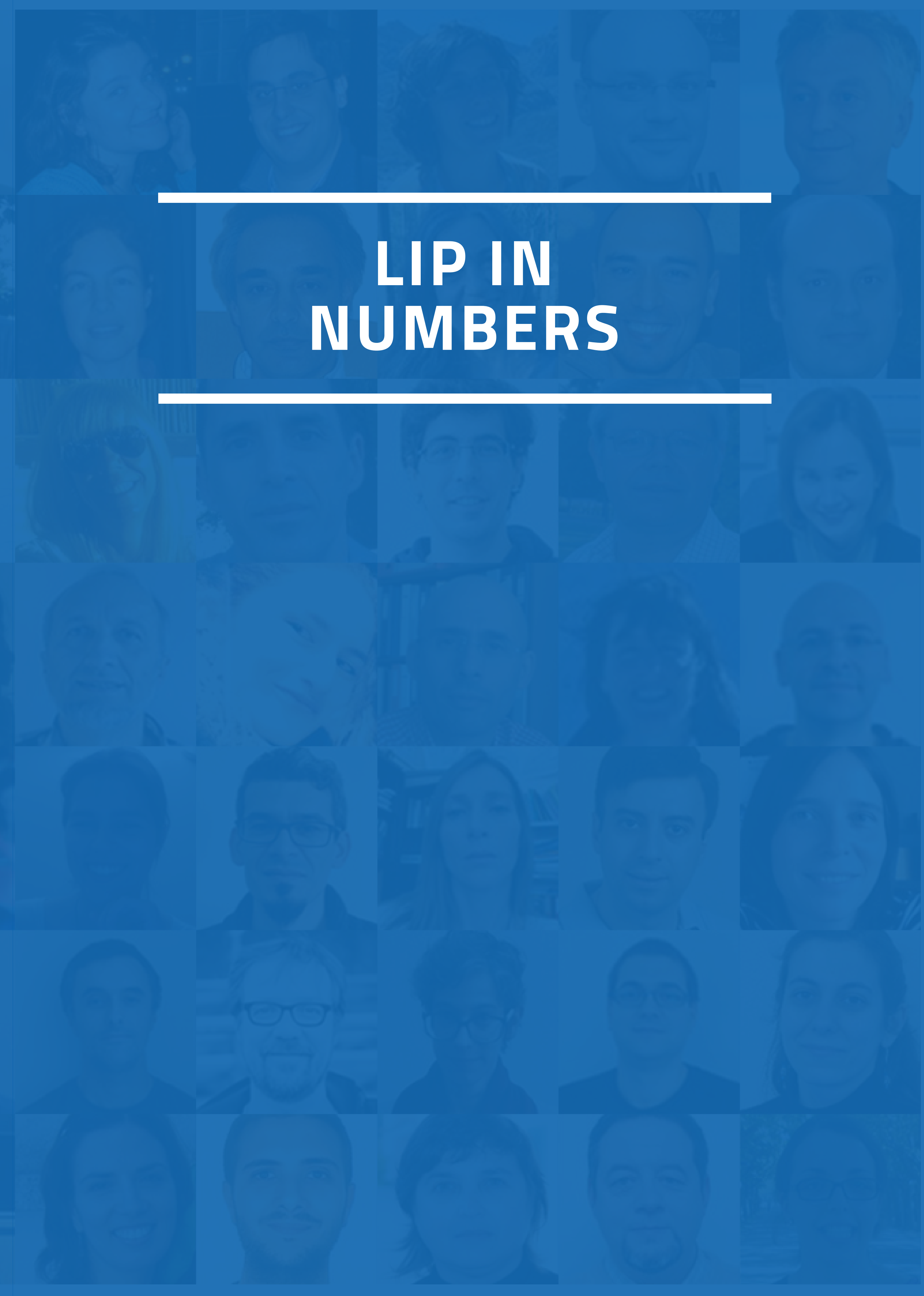
November 2018
**TRISTAN RPC telescope on its way to Antarctica aboard the Sarmiento de Gamboa scientific vessel**

November 2018
**COMPASS 2018 data taking completed**

December 2018
**PhD student from LIP Minho Ana Peixoto awarded an ATLAS PhD Grant**

December 2018
**End of LHC Run II**

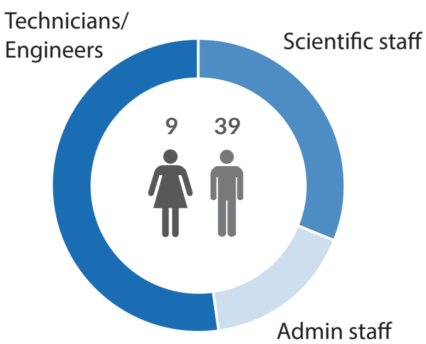




# LIP IN NUMBERS

# HUMAN RESOURCES

## STAFF

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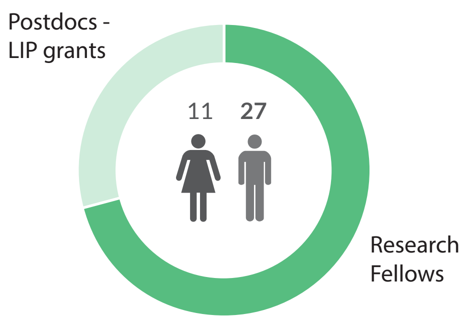
48
TOTAL

| | Women | Men |
|---|---|---|
| Technicians/ Engineers | 0 | 25 |
| Scientific staff | 3 | 12 |
| Admin staff | 6 | 2 |

## FIXED-TERM RESEARCHERS

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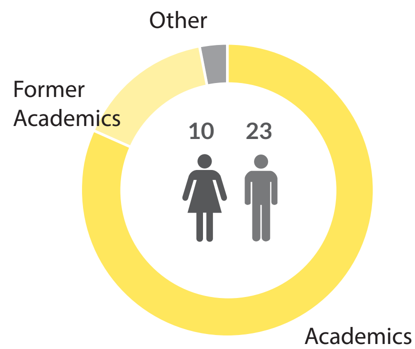
38
TOTAL

| | Women | Men |
|---|---|---|
| Research Fellows | 7 | 20 |
| Postdocs LIP grants | 4 | 7 |

## UNPAID

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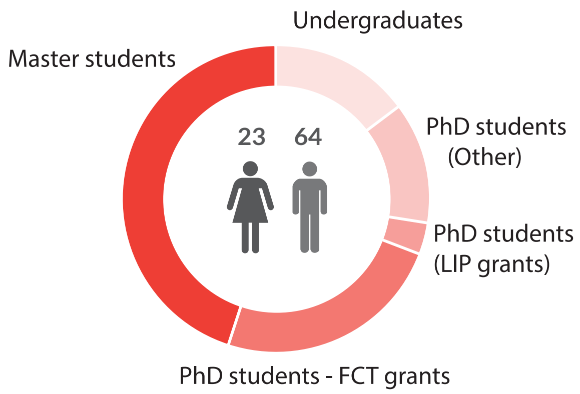
33
TOTAL

| | Women | Men |
|---|---|---|
| Academics | 6 | 21 |
| Former Academics | 4 | 1 |
| Other | 0 | 1 |

## TOTAL 206

| Women | Men |
|---|---|
| 53 | 153 |

## STUDENTS

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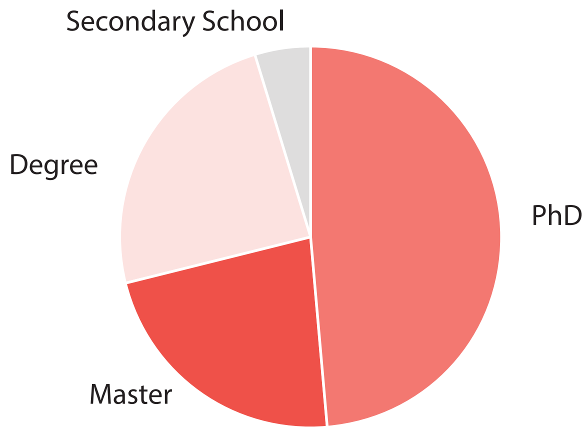
87

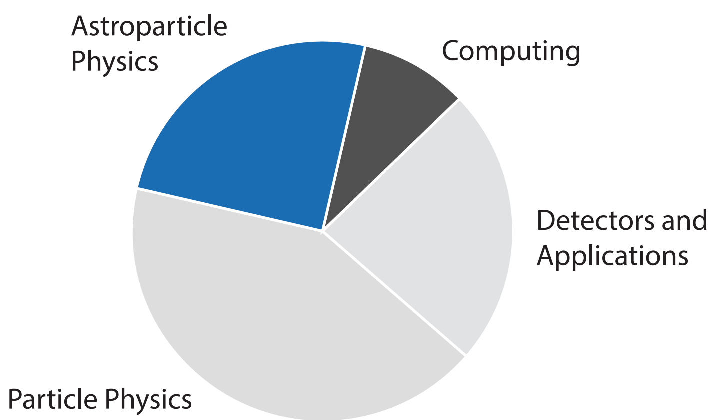
TOTAL

| | | |
|---|---|---|
| Master students | 8 | 31 |
| PhD students FCT grants | 6 | 15 |
| PhD students LIP grants | 1 | 2 |
| PhD students Other | 3 | 8 |
| Undergraduates | 5 | 8 |

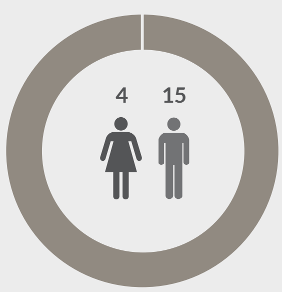
## DISTRIBUTION BY ACADEMIC DEGREE




## DISTRIBUTION BY RESEARCH AREA




## EXTERNAL COLLABORATORS

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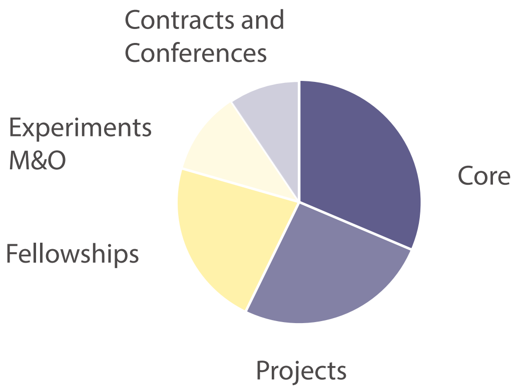
19

TOTAL

# FINANCES

## GENERAL FUNDING




1.7M
CORE FUNDING

1.4M
PROJECT-BASED

1.2M
FELLOWSHIPS

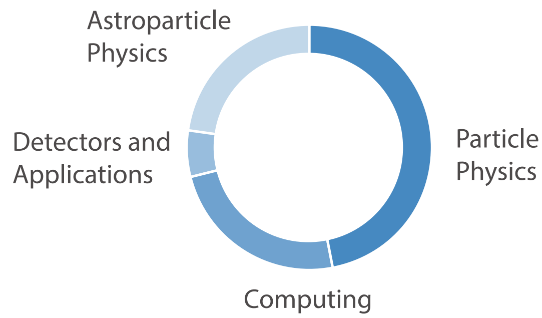
0.6M
EXPERIMENTS M&O

0.5M
CONTRACTS AND CONFERENCES

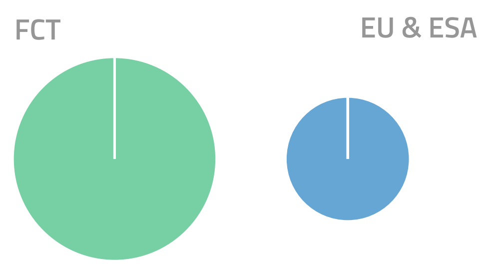
**TOTAL**
5.4M €

## PROJECT AND CONTRACT-BASED FUNDING

### BY RESEARCH AREA

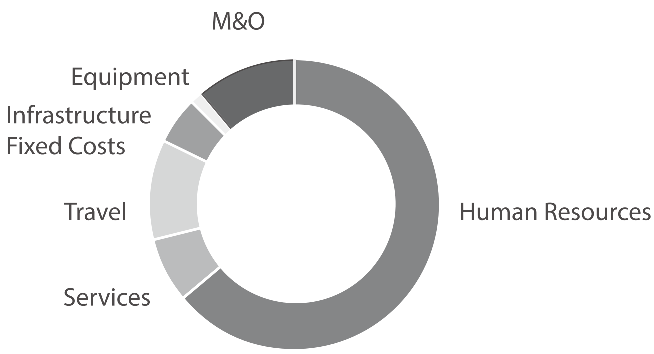



### BY ORIGIN




TOTAL
1.4M €

# COSTS




## HUMAN RESOURCES

STAFF 1.6M

FIXED-TERM RESEARCHERS 1.9M

## SERVICES AND OTHER EXPENSES

0.4M

## TRAVEL

0.6M

## EXPERIMENTS M&O

0.6M

## INFRASTRUCTURE FIXED COSTS

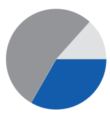
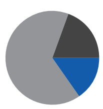
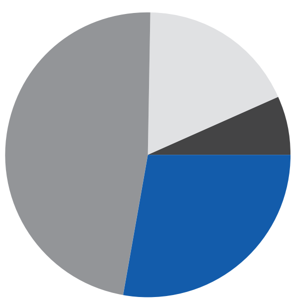
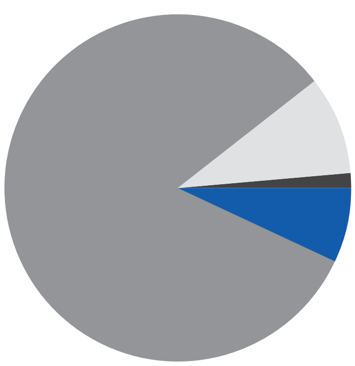
0.3M

## EQUIPMENT

0.07M

# SCIENTIFIC OUTPUT 2018

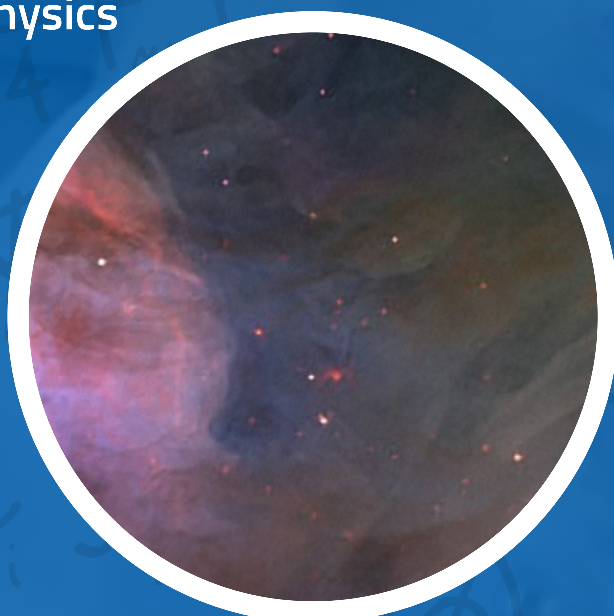
(Numbers in brackets are the integral of the last three years)

| | | Particle Physics | Astroparticle Physics |
|---|---|---|---|
| Books, Reports and Proposals |  | 8 (11) | 1 (2) |
| PhD Theses |  | 0 (9) | 0 (1) |
| Master Theses |  | 6 (16) | 1 (7) |
| Proceedings |  | 16 (51) | 10 (18) |
| Notes |  | 17 (53) | 4 (21) |
| Presentations |  | 115 (265) | 67 (147) |
| Papers in refereed journals |  | 294 (708) | 25 (77) |

| Detectors and Applications | Computing | TOTAL |
|---|---|---|
| 0 (1) | 0 (3) | **9** (17) |
| 3 (6) | 0 (0) | **3** (16) |
| 1 (12) | 0 (1) | **8** (36) |
| 4 (33) | 0 (4) | **30** (106) |
| 0 (8) | 5 (9) | **26** (91) |
| 43 (99) | 16 (33) | **241** (544) |
| 33 (72) | 4 (9) | **356** (866) |

Astroparticle Physics | Particle Physics | Detectors and Applications | Computing

## Experimental particle and astroparticle physics



# RESEARCH AT LIP

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

**Computing**

## Experimental particle and astroparticle physics

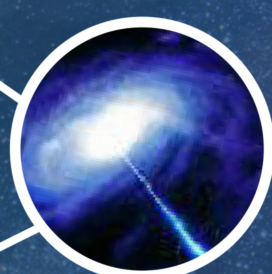
## Development of new instruments and methods

## LHC experiments and phenomenology

- ATLAS
- CMS
- Pheno

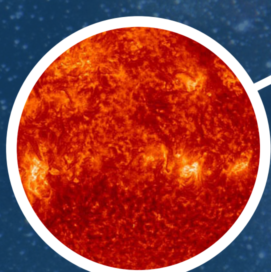
## Structure of matter

- PARTONS AND QCD
- LERHI
  - HADES
  - NUC-RIA



## Cosmic rays

- AMS
- Auger
- LATTES



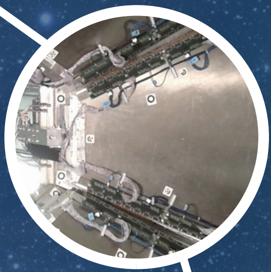
## Dark matter and neutrinos

- LUX/LZ
- SNO+ / DUNE
- SHiP

# RESEARCH

## Computing

- Distributed Computing and Digital Infrastructures
- Advanced Computing



## Detectors for particle and nuclear physics

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

## Health and biomedical applications

- OR Imaging
- Gamma Cameras
- Dosimetry

## Space applications

- Space Rad
- i-Astro

# Experimental particle and astroparticle physics

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

Experimental particle physics seeks always deeper into the universe – its constituents and workings at the most elementary level, its origin and evolution.

LIP is deeply involved in the CERN LHC endeavor, contributing from the very beginning to the two largest LHC experiments, ATLAS and CMS. With these fantastic scientific instruments we are studying Nature in many ways, from deepening our understanding of the Higgs boson to searching for new physics or recreating the conditions that existed just after the big bang. To contribute to these searches, the LIP Phenomenology group creates strong links between experimental and theoretical particle physics. At the same time, we are very actively improving our experiments, to respond to future challenges of running at higher LHC luminosities.

We still have a lot to discover about the ways in which elementary quarks and gluons work together to form the particles we observe, and that's the focus of LIP's Structure of Matter line of research. Our Partons and QCD group is currently involved in the COMPASS experiment, designed to study hadron structure, as well as in the preparation of the next steps in CERN's fixed target experimental programme; LIP's Low Energy Reactions with Hadrons and Ions (LERHI) group is the only Portuguese experimental team preparing to explore the frontier between nuclear and particle physics at the new FAIR facility at the GSI.

Experimental particle physics is conducted in ever more powerful accelerators, but also in astroparticle physics experiments, detecting particles that come to us from the cosmos. The quest for dark matter, a deeper understanding of the elusive neutrinos, or the origin and nature of cosmic rays are among the great challenges of particle physics for the next decades. LIP is part of these challenges through its engagement in some of the main international collaborations, including SNO+ at SNOLAB in Canada, LZ at the SURF Laboratory in the USA, the Pierre Auger Observatory in Argentina and the Alpha Magnetic Spectrometer in the ISS.

Recently embraced projects are the participation in DUNE, the main neutrino experiment of the next decade, and in SHiP, a new general-purpose experiment to be installed in a beam dump facility at the SPS to search for hidden particles.

EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

# LHC experiments and phenomenology

## Physics at the energy frontier

*In the past year, the LHC completed a very successful second physics run (LHC Run II). Both the ATLAS and CMS experiments have accumulated more than 60 $fb^{-1}$ proton collision data in 2018, bringing the Run II total up to about 150 $fb^{-1}$ per experiment. These data were collected at a centre of mass energy of 13 TeV, the energy frontier in collider experiments worldwide, allowing unique opportunities to probe Nature at the most intimate level. The ATLAS and CMS groups at LIP made good use of this opportunity to expand our knowledge of particle physics. In addition to proton collision data, the LHC has accumulated around 1.8 $fb^{-1}$ of lead-lead collision data in 2018, which will be useful in understanding the physics of quark-gluon plasma. LIP members were deeply involved in analysing all these data to extract exciting new physics results. But also in operating the detectors, developing their trigger, data acquisition system, event reconstruction algorithms, detector control tools, and in various R&D efforts to prepare for the future upgrades of the LHC experiments. The first phase of this upgrade has started and will last until the end of the LHC Run III, which will take place from 2021 to 2024. The High-Luminosity LHC phase (HL-LHC) will start in 2026 after another long shutdown. In parallel with the experimental progress at the LHC, LIP's phenomenology group has established itself during the past year. It has consolidated expertise that was previously scattered in different groups into a dynamic community dedicated to bridging the gap between theoretical studies and the experimental activity at LIP. It complements the experimental activity, which is in LIP's DNA, in a symbiotic relationship that will allow us to grow further.*

### Experimental Particle Physics

**Higgs: the year of Yukawa interactions**

Since the Higgs boson discovery in 2012, by the ATLAS and CMS experiments, a staggering amount of work was devoted to the detailed study of this unique particle. But it was only in 2018 that the direct coupling of the Higgs with the heaviest quarks, top and b, was clearly observed. Both ATLAS and CMS have achieved 5$\sigma$ observations of the Higgs boson produced in association with a top-quark pair. This demonstrates the largest Yukawa coupling of the Higgs to fermions in the Standard Model and constitutes one of the main goals in the Run II Higgs programme. Not only the top, but also the b quark was demonstrated to couple to the Higgs boson, through the observation of the decay to a b-quark pair, in the associated production mode with a W or Z boson, which was also firmly established by ATLAS. The decay channel to b quarks corresponds to the largest Higgs decay branching ratio. Its clear observation therefore poses an important constraint on the space available for new physics. The ATLAS team at LIP has contributed to both channels over several years, in areas ranging from jet reconstruction to statistical combinations and multivariate analysis methods, to the determination of important sources of background. The team is now involved in studies that make use of these channels to probe deeper into the detailed nature of the Higgs boson, for example examining the sign of the Yukawa coupling to b quarks or the CP quantum numbers of top-Higgs interactions, and projecting experimental sensitivity to future High Luminosity running. The CMS team is also investigating several Higgs channels, involving decays to tau leptons and charged Higgs searches, di-Higgs production that will constrain the shape of the Higgs potential, decays to heavy flavour hadrons to access the Yukawa couplings to second generation quarks, and associated production with the elusive dark matter particles. In the framework of a European training network, the team is spearheading advanced machine learning techniques, leading to important gains in experimental sensitivity, to apply them to Higgs searches.

**Top: the heavy weight**

The LHC is a top quark factory, providing the best opportunity for detailed measurements of the heaviest of fundamental particles. Its mass also makes the top quark a likely window to observe subtle effects of new physics, not described by the Standard Model of particle physics. It has long been a particular specialty of LIP's ATLAS and CMS groups, which have been deeply involved in important top-quark analyses. The CMS team is currently dedicated to the LHC Run II measurement of the top-quark pair production cross section with top decays to tau leptons. In the future, it plans to search for dark matter in top-like events. In 2018, the ATLAS team has continued to develop a measurement of the suppressed decay of the top-quark to an s quark and a W boson, and played a leading role in the effective field theory interpretation of top quark measurements in the LHC Top Working Group.

**Super searches for Supersymmetry**

Supersymmetric theories are a very popular way to circumvent certain shortcomings of the Standard Model. The weakly interacting and stable lightest supersymmetric particle would also be a perfect candidate to explain the mysterious dark matter, which is known to exist in abundance in the Universe around us. In 2018, the CMS group has completed a search for a light stop, the super-partner of the top quark, using LHC Run II collision data from 2016. This search has been published as a CMS publication. No signal of the stop was found, but new lower limits were determined for its mass. The team has also started the analysis of 2017 data in this channel.

**Unknown unknowns: exotic physics**

The ATLAS LIP team has been developing a strong expertise in searches for new physics, with a focus on heavy vector-like quarks, whose existence would account for the unexpectedly low value of the Higgs mass, one of the lingering mysteries in this area. In 2018 two analyses were published by ATLAS with leading contributions from the group: a search for vector-like quarks decaying to a b or a top quark and a Z boson, and a search for Flavour-Changing Neutral Current decays of the top quark. The team has also finished a search for top quarks accompanied by missing transverse energy, which was submitted for publication. The group has also contributed to an ATLAS publication combining several vector-like quark searches, which was highlighted as Editor's Suggestion in Physics Review Letters and to the ATLAS paper on the combination of the searches for mediator-based dark matter and scalar dark energy models, which was submitted for publication in JHEP.

**The flavour of rare decays**

The CMS team has important expertise in the measurement of rare decays of heavy hadrons, and was deeply involved in the observation of the extremely rare $B_s^0 \rightarrow \mu+\mu-$ and the search for the even rarer $B^0 \rightarrow \mu+\mu-$ decays, one of the physics highlights in 2015/16. In 2018 the team has made an important contribution to the analysis of this channel by studying the b-quark fragmentation-fraction ratio, allowing to reduce a large contribution to the systematic uncertainty of the measured $B_s^0 \rightarrow \mu+\mu-$ branching fraction. The analysis of 2016 data is currently under review by the collaboration and the team has initiated the analysis of 2017 data. The CMS team also has a long history of studies of quarkonium production. In 2018 the group continued the measurement of the polarization of the $\chi_{c1}$ and $\chi_{c2}$ states, which is approaching completion. Phenomenological studies of quarkonium measurements, to better understand the mechanisms of hadron formation in QCD have been pursued at LIP in a collaboration between the CMS and Phenomenology groups. In 2017, the team had uncovered a previously unnoticed scaling behaviour followed by quarkonia. This observation provides powerful guidance for experimental studies in this area.

**The hot Universe – Hadronic matter and heavy ion physics**

The LHC provides unique opportunities to study heavy-ion collisions and observe the Quark Gluon Plasma (QGP), which existed in the hot and dense medium of the very early Universe. The ATLAS and CMS teams are primarily involved in exploring the heavy b-quarks as probes of the QGP. Hadronic jets in very energetic heavy ion collisions are invaluable probes for this study, carrying the signature of quark interactions as they cross the QGP medium. The ATLAS team is pursuing studies using hadronic jets initiated by heavy b quarks to probe the dense quark-gluon plasma. In 2018, the group was involved in the analysis of Pb+Pb collision data, from the development of algorithms to identify b--initiated jets to the development of the trigger selection to make good use of such data. The CMS team studies fully reconstructed b-quark mesons to study the QGP, using LHC Run2 heavy-ion collision data for the first time. The team has produced a first measurement of B meson production using data from 2015, which has been published, and will now search for Bs signals using the full Pb+Pb dataset from Run II. In parallel, Pb+Pb Run2 data is used to further characterise the pattern of sequential quarkonium suppression, a phenomenon whose discovery with Run1 data was led  data by researchers at LIP.

## Tools of the trade — Detector operation and upgrade

In addition to the physics analysis activity during 2018, the ATLAS and CMS teams at LIP were very actively involved in running their experiments, in this final year of Run II. Both groups are also involved in the upgrade of each experiment. The LHC will resume operation in 2021, with around twice the current luminosity, or rate of collisions. A second phase, known as High--Luminosity LHC (HL-LHC), will start by 2026 with even higher luminosity, with the goal of collecting around 30 times more data than has been accumulated so far.

Both the ATLAS and CMS teams at LIP have made crucial contributions to the respective experiment and are involved in their continuous upgrades. CMS and ATLAS have both installed forward proton spectrometers, located a few hundred meters from their main detectors, very near the beam line. The LIP group is leading the CMS-Totem Precision Proton Spectrometer, now called PPS and fully integrated as a subdetector of CMS. The past year was very successful for the project, with the PPS collecting over 100 $fb^{-1}$ of data. An article was published, led by LIP members, which documents the first observation of lepton pairs observed in the CMS detector accompanied by protons detected in the PPS spectrometer, a process known as central exclusive production. Team members are now pursuing related analyses of two-photon production of W bosons and top quarks. The ATLAS Forward Proton spectrometer (AFP) was successfully operated in 2018, with the ATLAS team at LIP involved in the development and maintenance of its detector control and trigger systems.

The ATLAS team was from the start responsible for the optical readout system of the hadronic calorimeter (TileCal). The group holds important responsibilities in its operation and upgrade, including the detector control system and the monitoring of its response. In 2018 the team has made leading contributions, studying the degradation in light response due to radiation damage, optimizing the calibration methods, preparing wavelength-shifting optical fibres to be installed during the current shutdown, and developing the first prototype board for High Voltage (HV) distribution, a system which will be completely replaced under LIP's responsibility. The HV prototype board was tested both at LOMAC and at CERN, leading to an improved design. Besides electronics boards, the system will use special reduced profile cables produced in Portuguese industry. The group is also heavily involved in the ATLAS trigger system, with leading contributions to the software and event selection. Recent involvement includes developing a parallelized version of the time-consuming calorimeter cluster reconstruction to run in general-purpose graphical processors. During the past year, the ATLAS team has initiated a contribution to the future Hardware Tracking for the Trigger (HTT), a hardware tracking co-processor that will allow the reconstruction of tracks for use by trigger algorithms at rates up to 1 MHz.

The CMS team is deeply involved in the development of the technologies that will allow a successful upgrade of the experiment for operation in the challenging HL-LHC environment. In 2018 the LIP group increased its involvement in the Minimum-ionizing particle Timing Detector (MTD), assuming responsibilities in the front-end readout system. For this new detector, that will provide excellent timing resolution, the team is developing a custom integrated circuit in 110 nm CMOS technology. It will be integrated with scintillating detector modules and its performance further accessed in beam-test facilities. The team has also initiated a contribution to the development of the new Electromagnetic CALorimeter readout system, based on a fast amplifier and a new, fast and low power analog to digital converter. These contributions involve Portuguese industry in this high-end technological development activity. The CMS team is also involved in the development and supply of a new low voltage regulator resistant to radiation for the new High-Granularity Calorimeter that will completely replace the current electromagnetic calorimeter end-caps. In 2018 the specifications of this regulator were established and an industrial supplier is currently being searched.

## Phenomenology

The LIP Phenomenology group, created at the end of 2017, inherited very valuable expertise from the previous LHC Phenomenology and Heavy Ion Phenomenology groups. This group has activity bridging theory and experiment that, while independent, is centred on areas in which LIP has active experimental activities. It represents an important added value in these areas, coalescing scattered activities under a more coherent framework that has already been bearing fruits. 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. The LIP Phenomenology Group will continue to grow around consolidated lines of work in: heavy-ion phenomenology, exploring sub-structure properties of jets and their modifications by the quark-gluon plasma; heavy quarkonium, exploring implications of simple scaling patterns or the sequential suppression of quarkonia in nucleus-nucleus collisions; top-quark and Higgs, exploring the top-Higgs associated production as a probe of the Higgs sector or top-quark anomalous couplings in future colliders; effective field theory based searches for new physics; and exotic physics, exploring vector-like quarks in composite Higgs models, among others.
The near future of the High Energy frontier of particle physics will surely include the continued exploitation of the High Luminosity LHC (HL-LHC), and the LIP Phenomenology Group will be a fundamental asset in achieving an optimal scientific strategy for this endeavour. After that, a High Energy-LHC (HE-LHC) phase is a possibility, employing superconducting magnets that are currently under development to reach centre of mass energies around 30 TeV. In 2018 LIP has taken part, through the ATLAS, CMS and Phenomenology groups, in detailed studies contributing to the HL/HE-LHC scientific case, where LIP members participated in three of the five working groups, on Standard Model physics, Higgs physics, and High-Density QCD. The LIP community was also actively involved in the definition of the scientific case for the Future Circular Collider (FCC), a major international collaborative study of a possible circular collider to be built at CERN. Here, LIP members have contributed to the Higgs and detector studies, in proposing top quarks as new experimental probes to study the quark-gluon plasma time evolution, a topic that features prominently in the FCC conceptual design report.

SELECTED
## References


"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 decays and V H production with the ATLAS detector", ATLAS Collaboration, Phys. Lett. B 786 (2018) 59-86

"Combination of the Searches for Pair-Produced Vectorlike Partners of the Third-Generation Quarks at sqrt(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

"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

"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. Beirão et al, CMS Collaboration, 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)

"Universal kinematic scaling as a probe of factorized long-distance effects in high-energy quarkonium production", Pietro Faccioli, Carlos Lourenço, Mariana Araújo, João Seixas, Eur. Phys. J. C 78 (2018) 118

"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

"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

"From identical S- and P-wave p(T) spectra to maximally distinct polarizations: probing NRQCD with chi states", Pietro Faccioli, Carlos Lourenço, Mariana Araújo, João Seixas, Ilse Kraetschmer, Valentin Knunz, Eur. Phys. J. C 78 (2018) 268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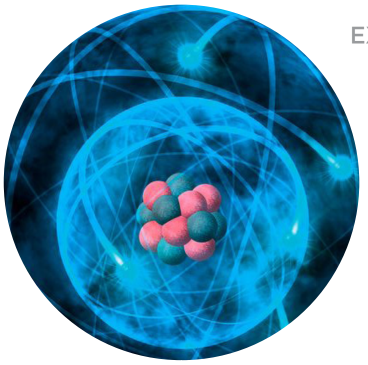

EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

# Structure of matter

## Looking inside hadronic matter

*We still have a lot to discover about the ways in which elementary quarks and gluons work together to form the particles we observe, and that's the focus of LIP's structure of matter research line. LIP's Partons and QCD (PQCD) group is currently involved in the COMPASS experiment, designed to study hadron structure, as well as in the preparation of the next steps in CERN's fixed target experimental programme; LIP's Low Energy Reactions with Hadrons and Ions group (LERHI) is the only Portuguese experimental team preparing to explore the frontier between nuclear and particle physics at the new FAIR facility at the GSI, and is deeply involved in the HADES and R$^3$B experiments.*

### COMPASS – the workings of nucleons

The LIP PQCD group is heir to a long tradition in CERN's fixed target experimental programme, starting in the 1980s with the heavy ion experiments NA38 and later NA50. The group now concentrates on the COMPASS experiment. Major aims of the experiment are to discover how quarks and gluons contribute to the spin of the proton and to investigate the spectrum of particles that quarks and gluons can form. To do so, they collide high intensity muon or hadron beams with a polarized target at a temperature of -273 ºC. The experiment uses beams from the SPS accelerator (Super Proton Synchrotron). The target is followed by a two stage spectrometer observing the particles that result from the collision. 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 three-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 group in COMPASS is the sole responsible for the complex Detector Control System (DCS), known at CERN for its outstanding reliability. 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) and provides the on-call service during the approximately 7 months/year of data-taking. During 2019 and 2020 there is a long shutdown period at CERN. This interruption offers the timely opportunity to upgrade the DCS of COMPASS, preparing it for the 2021 data-taking period.

The group is also involved in the key analyses of the COMPASS collaboration, and is a reference in the measurements using the Drell-Yan (DY) process, the production of lepton pairs in hadron collisions. The 2018 data-taking was devoted to the study of pion-induced DY on a transversely polarised proton target. The analysis of the 2015 data, taken in similar conditions, gave a first hint of the importance of parton transverse momentum dependent effects to the nucleon dynamics. The 2018 collected sample is expected to significantly improve the statistical significance of the observed signals. The development of machine learning analysis techniques adapted to polarized DY, lead by LIP group members, is a strong commitment for the coming years. 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 hadron multiplicities and fragmentation functions. COMPASS is presently the only DIS experiment in the world with a beam energy above 20 GeV, and thus is a 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.

The present scientific programme of COMPASS will be completed with the 2021 run. The LIP group is 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. A Letter of Intent "A New QCD facility at the M2 beam line of the CERN SPS: COMPASS++/AMBER" was recently submitted to the CERN SPSC. This 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.

## LERHI – At the frontier between nuclear and particle physics

LIP's LERHI group joins two teams with different background and is built around a solid expertise in instrumentation for particle detection and the study of nuclear reactions and hadronic processes at medium energies (a few MeV to a few GeV per nucleon). It is focused on experiments based at FAIR-Facility for Antiproton and Ion Research, the new generation facility at GSI, and at CERN. LIP is a member of two of the four pillars of FAIR: HADES and $R^3B$, contributing both in R&D, construction and operation of detectors and in physics studies. The accelerator infrastructure at GSI was shutdown during the last five years and resumed operation in 2018. The performed upgrades will put into operation the SIS100 synchrotron at the new FAIR facility, providing higher beam energies and intensities. Both HADES and $R^3B$ are among the first experiments to start operation, in the so-called Phase-0 of FAIR. Due to problems during the start up of the accelerator infrastructure, the first Ag+Ag production beam run scheduled for the second half of 2018 was shifted to first half of 2019.

### HADES – the secrets of high densities

HADES is currently the only experiment studying the region of the QCD phase diagram of very high net-baryon densities and low temperatures. Such conditions should allow to produce a state of matter resembling the one 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, and may shed light on the mechanism responsible for the mass generation in hadrons. Di-electrons originating from in-medium hadron decays, and rare strange hadrons (kaons, hyperons), are the main probes measured in the experiment. The LIP group plays a leading role in this area, as we developed one of the independent di-lepton analyses, the HADES golden channel.

HADES will be one of the first experiments to be operational at FAIR. 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. After the dismantling of the RPC-TOF-W in 2017, its re-installation in the new ECAL main frame in 2018 was a major operation carried out by the LIP team.The RPCs, together with all subsystems and cabling, were moved and reinstalled. In order to increase the acceptance of the spectrometer, a new detector is being built to cover the very low polar angles in the forward region. This new Forward Detector (FD), is composed by a tracking detector and a TOF detector. The LIP group is in charge of the simulation, design and construction of the TOF detector of the FD, the RPC-TOF-FD. A prototype module of RPC-TOF-FD was designed and built in close collaboration with the LIP Detectors Laboratory and Mechanical workshop, and the LIP SHiP and RPC R&D groups. After validation with cosmic rays, the prototype was exposed to negative pions of 8 GeV at the CERN T9 test beam area. The results show an average efficiency and timing accuracy of 98% and 54 ps and no noticeable dependence on position over the entire area. The final detector will consist of four such modules. In collaboration with the HADES Multi Drift Chamber (MDC) group, an MDC prototype was designed and assembled in order to explore the lower limits of the drift cell size. Preliminary tests are under way.

### $R^3B$ and beyond

The LIP group has a very active role in the study of break-up reactions of nuclear halo systems on a proton target and is involved in low-energy reaction experiments of interest for nuclear astrophysics at the HiE-ISOLDE/CERN facility. Concerning the participation in the $R^3B$ collaboration at FAIR, the group developed both instrumentation work and simulation and analysis tools for the $R^3B$ CALIFA calorimeter. The preparation for the FAIR Phase-0 experiment S444, planned to benchmark the new detection systems of $R^3B$, started during spring 2018. Our team joined these efforts on-site. This information will be very relevant for the analysis of data obtained from reactions on radioactive beams at FAIR. Additional tests of CALIFA modules will be performed in Lisbon during 2019, in collaboration with the University of Santiago de Compostela. Continuing on the path of studying breakup reactions on halo nuclei, the group is directly involved in two experimental proposals using the new experimental devices during 2019. The first series of experiments, expected in the fall of 2018, were delayed to the beginning of 2019, due to technical problems at FAIR.

The line of work foreseen at ISOLDE/CERN reached remarkable achievements during 2018 and has an exciting year ahead. Due to the large number of beam hours already approved for 2018 at ISOLDE, and considering the long shutdown (LS2) at CERN, the study of nuclear reactions in inverse kinematics planned in the letter of intent submitted last year was redirected to the LNS-INFN stable beam facility in Catania, Italy. 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 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. Regarding the participation at ISOLDE/CERN, a Letter of Intent towards new nuclear astrophysics experiments was submitted. This grouped a consortium to continue the participation at ISOLDE for the upcoming 2 years, which was approved for funding. Specific experimental targets were developed in Lisbon for the IS619 experiment.

SELECTED
## References

"Transverse-momentum-dependent multiplicities of charged hadrons in muon-deuteron deep inelastic scattering", COMPASS Collab., Phys. Rev. D 97, 032006 (2018)

"K− over K+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual-photon energy ", R. Akhunzyanov et al., COMPASS Collab., Physics Letters B 786(2018) 390–398

"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)

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EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

# Cosmic rays

## Messengers from outer space

*Planet Earth is constantly being struck by cosmic rays — particles expelled by distant stars and galaxies. These messengers from outer space bring much information about the history and composition of the Universe. Cosmic ray physics is an active field of research, with many ongoing experiments addressing questions on their origin, nature, acceleration and propagation. The very wide range of energies of cosmic rays implies that different detection methods are used, from space-based experiments in the GeV/TeV, range to ground-based giant air shower detectors in the EeV range. The LIP cosmic ray group covers much of this range, as it is committed to the Alpha Magnetic Spectrometer (AMS) and to the Pierre Auger Observatory. The group has also unique conditions to play a leading role in R&D of future detectors, and is involved in the LATTES project for a future high-energy gamma-ray observatory in the Southern hemisphere.*

### AMS – a particle detector in Space

Since 1998 LIP is part of the broad international collaboration that designed and operates the Alpha Magnetic Spectrometer (AMS). The project had two 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. Since then, a large set of data has been gathered at a continuous rate of around 45 million events/day, corresponding now to about 130 billion events recorded. This detector can identify cosmic ray particles before they interact with Earth's atmosphere. AMS studies cosmic ray fluxes in detail, but it also searches for antimatter nuclei and dark matter in the Universe. AMS remains a unique observatory in space and is expected to continue taking data up to at least 2024. LIP had an important role in the design and construction of the Ring Imaging Cherenkov (RICH) detector. Today, the group holds responsibilities on the RICH operations, monitoring and on the development, implementation and maintenance of a set of algorithms for reconstructing the particle's electric charge and velocity with the RICH. 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.

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. The LIP group is involved in the study of the solar modulation of the cosmic rays and in its interpretation under solar modulation models, studying not only the correlation between the sun's activity and the cosmic ray flux but also the intrinsic propagation mechanisms present in solar modulation.

The group has also been involved in data analysis with particle identification, based on advanced analysis techniques. Such tools can be used on anti-proton/electron separation and on isotope identification. Observations of light isotopes provide information on the origin of cosmic rays and their propagation in the galaxy. Some isotopes are of primary origin, while others are produced by collisions of cosmic primaries with the interstellar matter. The study of unstable isotopes, like $^{10}$Be, is essential to disentangle the size of the galaxy halo from the diffusion coefficient, giving the strength of the diffusion process cosmic rays undergo. These are two key parameters for cosmic rays propagation.

### Auger – the most energetic particles in the Universe

The Pierre Auger Observatory covers an area of 3000 km$^2$ in the Pampa Amarilla, Argentina. It consists of 1600 detectors separated by 1.5 km that sample the showers of millions of particles produced when the highest energy cosmic rays hit the atmosphere. In dark nights, 27 telescopes detect the ultraviolet light emitted by the showers. The Observatory is taking data since 2004, and a number of breakthroughs have been achieved. Nevertheless, several open questions remain concerning the nature and origin of the highest energy cosmic rays. The observatory will continue operations until 2025 and is currently being upgraded, to enable a better understanding of the electromagnetic and muonic shower components. R&D for future cosmic ray detectors also takes place at the Observatory site.

The muon component plays a big role in unveiling the nature of the highest energy cosmic rays, as it can probe directly the hadronic component of the shower in its early stages. However, muons are only indirectly accessible even with the upgraded Auger detector. Sophisticated analysis will be necessary to separate them from the dominant electromagnetic signals. For this reason, a small part of the array will be equipped with extra detectors to understand and calibrate, at a lower energy, the measurements of the full array. 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 of showers. Low gas flux RPCs developed at LIP-Coimbra were built, in cooperation with São Carlos, Brazil and their installation is foreseen for 2019. Prototypes have been working on a regular basis at Malargüe. MARTA data will provide a deeper understanding of the Auger surface detectors response, for the validation and *in situ* test of the upgrade scintillators and for detailed shower studies at lower energies ($10^{18}$ eV, closer to the LHC centre-of-mass energies).

Concerning data analysis, the observation of more muons than expected from current models is one of the most intriguing questions raised by Auger data. Furthermore, the detailed study of both the electromagnetic and muonic shower components is crucial for the determination of the nature of the primary particle and to disentangle it from the modeling of hadron interactions. The LIP group is directly involved in this quest, exploiting hadron interactions at high energies through a window that is largely complementary to the LHC. The 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. 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. In the near future, the correlation between fundamental properties of the initial interactions and the different observables at ground will be further exploited. Following the published work, the group will investigate the precision with which measurement on fundamental properties at the highest energies can be made. The phenomenology related to the muon energy distribution will be further studied to understand its importance and the possibility to infer it using the new detectors. Strategies taking advantage of multi-detector measurements will be pursued.

## LATTES – at the top of the mountains

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 experiments the wide FoV 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 and be fully complementary to the large next generation imaging atmospheric Cherenkov telescope array, CTA.

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 at LIP in 2016-17 and published at the beginning of 2018. 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. Strong cooperation with the Auger and RPC R&D groups will continue in detector development. Data from the MARTA array will be of key importance, as well as the developments made in the electronics and data acquisition of RPC detectors.

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 of converging into a single collaboration able to find the human and financial resources necessary to build such an ambitious project. The project is conceptually and technologically innovative, but the LIP group has the conditions to give a significant contribution, due to its expertise in cosmic ray physics, detector simulation techniques

SELECTED
## References

"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

"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, et al. Eur. Phys. J. C (2018) 78:333

"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

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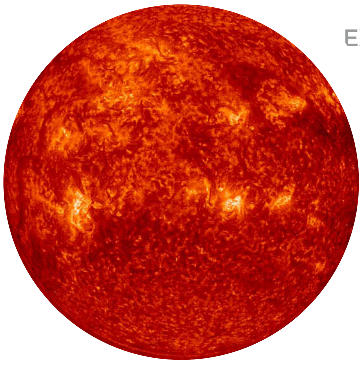

EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

# Dark matter and neutrinos

## Hunting for the most elusive particles

*The quest for dark matter and a deeper understanding of the elusive neutrinos are among the great challenges of particle physics for the next decades. LIP is part of these challenges through its engagement in some of the main international collaborations in this area: the neutrino experiment SNO+ at the SNOLAB laboratory in Canada, the dark matter detector LZ at the SURF Laboratory in the USA, and the recently embraced participations in DUNE, the main neutrino experiment of the next decade, and in SHiP, a general-purpose experiment proposed for CERN's SPS.*

### Searching for the dark side

According to the most recent experimental evidence, dark matter makes up 27% of the total density of the Universe. We have strong clues that dark matter is made of particles that interact very weakly. One of the ways to search for it is to use super-sensitive underground detectors to identify very rare interactions between dark matter particles that cross the Earth and normal matter particles. The LIP Dark Matter group joined the LUX experiment in 2010 and 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 have continued after decommission in 2017, resulting in over 20 scientific papers already published or in preparation. These papers cover a large variety of topics including the search for 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 $1.6 \times 10^{-48}$ $cm^2$ for a 40 GeV WIMP mass, roughly 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 LIP Dark Matter 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 neutrinoless double beta decay (NDBD, or $0\nu2\beta$) of $^{136}Xe$, the second most important physics goal of LZ.

#### SNO+

The Sudbury Neutrino Observatory (SNO) measured the oscillations of solar neutrinos, i.e., their transformations from one type to another (Nobel prize in Physics 2015). The detector is located 2 km deep underground, in SNOLAB, Canada. An acrylic sphere with 12 m diameter and 5 cm thickness, that contained 1000 tons of heavy water, is surrounded by 9500 light sensors. The SNO+ experiment follows from SNO, replacing the heavy water with liquid scintillator to increase the sensitivity to other neutrino physics signals. The LIP group joined the SNO experiment in 2005, and is a founding member of the SNO+ international collaboration. The main goal of the experiment is the search for neutrino-less double-beta decay, by loading the scintillator with large quantities of Tellurium. The observation of this process would be a breakthrough in the understanding of the nature of neutrinos, revealing that they are Majorana particles. Several other low-energy, low-background, physics topics are also part of its program: antineutrinos from nuclear reactors and the Earth's natural radioactivity, solar and supernova neutrinos, and searches for new physics.

In 2018, SNO+ has been taking data with the detector filled with water. 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. A milestone was the completion of the SNO+ LIP remote control room, from which we can now carry out SNO+ detector operator shifts. The scintillator fill is expected in 2019, and so the group's efforts will gradually shift from water phase to scintillator phase data analysis. Our prospects are thus to continue shifting our focus towards physics analyses, while maintaining our responsibilities in calibrations and 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 double beta decay search analyses. Ongoing re-analyses of SNO data are also expected to lead to physics publications in the near future.

### DUNE

The discoveries of the last few decades have brought neutrinos to the fore in seeking answers to fundamental questions about the composition and evolution of the Universe. DUNE will certainly be one of the great projects of the next decades in the search of these answers, studying in particular the mass hierarchy of neutrinos and CP violation.

In 2018, LIP joined the DUNE collaboration, with the goal of participating in the leading neutrino physics experiment of the next decade. 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 LAr TPC (ProtoDUNE) took beam test data and is now collecting cosmic rays at CERN; a double phase (liquid + gas) is under preparation also at CERN. Our activities will initially focus on design of the far detector calibration systems and operation/data analysis of the protoDUNE detectors at CERN. 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. The PI of theLIP team is presently leading the Calibration Consortium of DUNE. Operations and data analysis of protoDUNE are also strategic goals for the longer-term development of an expertise in LAr detectors at LIP.

### SHiP

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/c$^2$ to 200 MeV/c$^2$ 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 of neutrino-induced charm production.The experiment is expected to be approved in 2020 and start taking data in 2026. The LIP-SHiP group was created in 2018.

An important element of the SHiP spectrometer is the timing detector, a detector with 50 m$^2$ 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 based on the timing Resistive Plate Chamber (tRPC) technology. 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. A prototype module for the SHiP timing detector was designed and built in close collaboration with LIP's Detector Laboratory and Mechanical workshop. After validation with cosmic rays in Coimbra, the prototype was exposed to negative pions of 8 GeV in October 2018 at CERN's T9 test beam area. The results show an average efficiency and timing accuracy of 98% and 54 ps. The RPC detector is presently being included in the official software, FairSHiP, to study its impact on the various physics channels.

SELECTED
## References


"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

"Temperature quenching in LAB based liquid scintillator", A. Sörensen, S. Hans, A.R. Junghans, B.v. Krosigk, T. Kögler, V. Lozza, A. Wagner, M. Yeh, K. Zuber, Eur.Phys.J. C78 (2018) 9

"Tests of Lorentz invariance at the Sudbury Neutrino Observatory", SNO collaboration, Phys.Rev. D98 (2018) 112013


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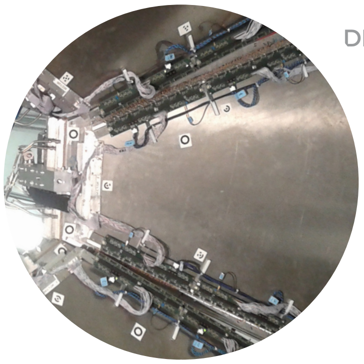
# Development of new instruments and methods

Radiation detectors are sensitive to the passage of particles and able to measure some of their characteristics. Throughout the history of particle physics, the development of ever more powerful detection technologies has played a crucial role in fostering new discoveries. Detector development involves not only the detecting device itself but the associated data acquisition and readout electronic system, as well as trigger and data processing tools.

The development of new instruments and methods related to experimental particle physics has been from its inception one of the main pillars of activity at LIP. Over the years, LIP has built a high level of expertise in key radiation detection technologies, supported by research on the fundamental processes involved. Our current activities include research on fundamental detection processes and applications of radiation detectors. Our specialities include Resistive Plate Chambers (RPC), gaseous and Xenon-based detectors, neutron detectors, optical fiber calorimeters and fast electronics for data acquisition systems.

LIP's expertise in planning, building and operating detectors for particle physics finds natural application in the fields of radiation therapy instrumentation, medical imaging and dosimetry. These areas are covered in multidisciplinary projects developed in collaboration with partners such as the ICNAS institute for nuclear health applications, the CTN/IST centre for nuclear technology, and several hospitals and medical research centres.

Space exploration is a natural area of application of particle physics technologies, especially in what concerns radiation detection instrumentation and the modeling of complex processes involving the interaction of radiation with matter. Over the last decades, LIP became a recognized partner in the space community. LIP is today a partner of the European Space Agency (ESA) in several planetary missions and consortia for the development of scientific instruments.



DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

# Detectors for particle and nuclear physics

## Technology to see the invisible

*The development of particle detectors and related instrumentation has been, from the start, one of the pillars of activity at LIP. Over the years LIP has built a high level of expertise in key radiation detection technologies, supported by research on the fundamental processes involved.*

### RPC R&D

Resistive Plate Chambers (RPC) are versatile detectors with a fast response, intrinsically radiation hard, and relatively low cost. Over the last years, LIP's RPC R&D group developed a set of coherent and ambitious lines of work that took the performance and the flexibility of RPCs to a new level. This expanded the range of RPC applications to several areas widely recognized as addressing societal challenges, from nuclear and particle physics to medical physics, from rugged outdoor muon detection systems to helium-free neutron detectors, confirming LIP as a world leader in the development, design and construction of RPCs.

The group presently works on a number of R&D lines. Time-Of-Flight RPCs (TOF-RPCs), providing high resolution measurement of position and time, continue to be one of the main technologies for the identification of particles, in high energy physics experiments whenever large detection areas are needed. The group is developing this technology based on an innovative concept for the construction of RPCs, achieving a reasonably low cost and reaching 98% efficiency with 50 ps time resolution and sub-milimetre spatial resolution. Such detectors are developed to be used in particle physics experiments in which LIP participates, namely HADES and SHiP, but this technology also finds direct application for example in muon tomography. Both transmission tomography (e.g. volcano and mine imaging) and scatter tomography (container scanning) are of interest to the group. As an example, a 4-layer TOFtracker device for muon tomography of cargo containers at harbours, for the HYDRONAV S.A company, has been constructed, integrated and deployed. A project for the construction of two cosmic ray telescopes for the monitoring of the stratosphere temperature was submitted by HYDRONAV in cooperation with LIP and recommended for funding. The system is a prototype for a future macro-scanner for cargo container scans.

Another line of work is the development of RCP-based devices for medical imaging through Positron Emission Tomography (PET). The RPC-PET technology has already been applied successfully in pre-clinical PET. A high-resolution, small animal RPC-PET scanner developed at LIP is installed at ICNAS since 2014. Hundreds of tests have been performed on mice, with goals such as studying the molecular mechanisms underlying degenerative diseases or testing new drugs that may be used to treat certain diseases. This technology has the potential to be applied in human brain PET and 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 reachable spatial resolution. A project "HiRezBrainPET: neurofunctional cerebral imaging by high resolution positron emission tomography (PET)" has been submitted and approved. It is led by the company ICNAS-Produção Unipessoal and has a strong participation of LIP.

Autonomous RPCs, able to operate outdoors, reliable, performant, and solar panel powered, are an extremely interesting technology for cosmic ray experiments. This line of work has also been very active in 2018. The construction, test and deployment on the Sarmiento de Gamboa scientific vessel of the TRISTAN cosmic ray telescope was accomplished successfully. The first latitudinal survey, from Spain to Antarctica, was finalized and preliminary data are available. Another ongoing project is the construction of the MARTA engineering array, equipping some of the water Cherenkov detectors of the Pierre Auger Observatory with RPCs for calibration and R&D purposes. The construction of the sensitive volumes and the integration in São Carlos, Brazil, with the locally-produced mechanics and wiring, are practically completed. The installation at the Auger site will be performed in 2019. Sealed RPCs would be a breakthrough in the field, and the LIP group is working towards this goal.

In addition to these main activities the group is involved in the development of high-rate RPCs and epi-thermal neutron position-sensitive RPCs. The group also keeps an interest on the modeling of RPC physics and other fundamental issues, such as gas mixture properties and detector ageing.

## Neutron Detectors

There is a widespread need for $^{3}$He-free Position Sensitive Neutron Detectors (PSNDs) with enhanced performance for applications ranging from neutron scattering science (NSS) to homeland security and well logging. The European Spallation Source (ESS), currently under construction, is a prime example and a driver of such need for high performance PSNDs to fully explore all its potential. Neutrons as a non-ionizing radiation cannot be detected directly, but only through the reaction products in converter materials. Only a few isotopes can be used for this purpose, with $^{3}$He being the most common. Nowadays, however, the $^{3}$He shortage results in a change of paradigm, which poses demanding challenges to develop new types of $^{3}$He-free neutron detectors, capable of satisfying high performance standards. $^{10}$B is one of the most promising alternative candidates to $^{3}$He. However the maximum detection efficiency achieved with a single layer of a solid neutron converter such as $^{10}B_4C$, is only about 5%. As a solution to face this challenge the LIP team proposed a new detector concept based on $^{10}B_4C$ coated RPCs, which takes advantage of the naturally layered configuration of RPCs. The feasibility of the concept was successfully demonstrated, and the work developed at LIP is now integrated into the Horizon-2020 EU research project Science & Innovation with Neutrons in Europe in 2020 (SINE2020).

Previously, a detector prototype with a stack of 10 double-gap RPCs lined with $^{10}$B (20 layers of $^{10}B_4C$ in total) was designed and built. The detector was tested with neutrons at TUM-FRMII (Germany). A detection efficiency of more than 50%, together with a 2D-spatial resolution of the order of 300 µm has been demonstrated. The results also demonstrated the capability of this novel type of neutron detector to measure the third coordinate with a high timing resolution, making this multilayer architecture very promising. However, the current counting rate limitation of these devices (~$10^3$ Hz/cm$^2$) is preventing widespread use of this technology for many applications. Also, the possibility to reach very low gamma ray sensitivity has to be demonstrated due to the strict signal-to-noise requirements typically set for this type of detector. To address these challenges, two main objectives have been established, and the group worked towards them in 2018: to boost the counting rate by a factor of 100; and to demonstrate that the sensitivity to gamma rays can be less than $10^{-5}$. Meeting these two objectives will render $^{10}$B-RPCs neutron detection technology one of the strongest candidates for future applications at neutron facilities, homeland security and industry.

In a parallel line of work, we are developing a high resolution PSND based on a $^{6}$Li-Glass scintillator readout by an array of SiPMs (Silicon Photomultipliers), in cooperation with ILL and a group from FZ Jülich (GE). This would be suitable for counting rates of the order of 1 MHz, well above the capability of $^{10}$B-RPCs, in application such as neutron reflectometry. Recently, in a test performed at ILL of a preliminary detector prototype built at LIP, we achieved a spatial resolution below 0.6 mm FWHM, by applying a statistical reconstruction method to compute position. A recently introduced new organic scintillator (EJ-270) is also being explored.

## R&D on gaseous and liquid Xenon detectors

Another speciality of LIP are detectors based on the use of xenon as the active material. The high density and high interaction cross sections with ionizing radiation make Xe an ideal detection medium for many applications, such as gamma radiation and dark matter searches. Although the energy ranges of interest of these experiments are different, from the detection point of view they have very much in common.

### Ion mobility measurements

The group also has unique expertise in the measurement and modelling of fundamental processes in gaseous and liquefied noble gas detectors. This is relevant in several areas, such as the modeling of gaseous radiation detectors, the understanding of pulse shape, and also in IMS (Ion Mobility Spectrometry), a technique used in a wide variety of applications, even for detecting narcotics and explosives. Data on ion mobility is especially important for improving the performance of large volume gaseous detectors, such as the ALICE and NEXT TPCs or Transition Radiation Detectors. This has created an increasing interest among the CERN community, and we are commited to study ion mobilities for specific gas mixtures. We have extended the positive ion mobility measurements to other mixtures of interest for large volume detectors.

### Liquid Xenon detectors

Our team is also focused on the processes triggered by particle interaction with liquid xenon and associated technologies, focusing on giving significant contributions to the future generation of liquid xenon detectors. The scope of our activities encompasses all the electronic, optical and molecular processes generated in a single- or double-phase liquid xenon detector due to particle interactions in the medium. Recently, a project has been approved for the group's participation in the CERN's detector R&D collaboration RD51. Our focus for the next few years will be studying satellite signals in liquid xenon double phase electroluminescence TPCs. We will develop and manufacture a benchtop setup for such studies and test different techniques of electronic excitation of xenon, and construction materials suitable for the ultraviolet wavelength region. In the framework of the LZ collaboration, the LIP group is involved in the measurement, simulation and modeling of reflectance and transmittance of materials for LZ.

## Scintillating Detectors and Optical Fibres

LIP has expertise in detectors based on radiation-hard scintillators and scintillating or wavelength-shifting (WLS) optical fibres. We decisively contributed to the ATLAS Tilecal calorimeter and to a number of other projects. LIP has experimental labs in Lisbon (LOMaC), dedicated to instrumentation for processing and characterization of optical wavelength shifting and scintillating fibres, plastic scintillators and photomultipliers.

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 replacement of the Tilecal 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 to the studies for scintillator based detectors for the Future Circular Collider. Studies using scintillators, WLS fibers and several photodetectors will be carried out. The third area corresponds to applications in microdosimetry, where the characterization of scintillating optical fibres is foreseen, in close collaboration with the LIP Dosimetry Group.

// CONTACTS

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Rui Marques, rui@coimbra.lip.pt

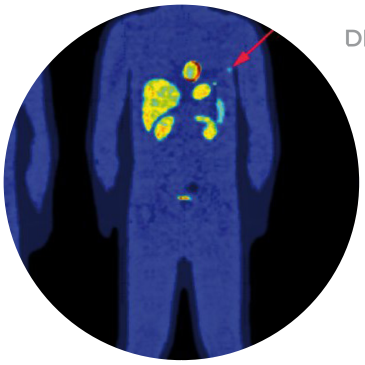
SELECTED
### References

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

"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

"Electron drift properties in high pressure gaseous xenon", A. Simon et al., J. Instrum. 13 (2018) P07013

"Study of the loss of xenon scintillation in xenon-trimethylamine mixtures", A. M. F. Trindade et al., Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 905 (2018) 22-28



DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

# Health and biomedical applications

## From physics labs to the hospital

*LIP's expertise in planning, building and operating detectors for particle physics finds natural application in the fields of radiation therapy instrumentation, medical imaging and dosimetry. These areas are covered in multidisciplinary projects developed in collaboration with partners such as the ICNAS institute for nuclear health applications, the CTN/IST centre for nuclear technology, and several hospitals and medical research centres.*

*In the next five years our partnership with ICNAS will be fundamental for our projects, especially RPC-PET and Ortho-CT. The installation at CTN/IST of a hadron therapy unit will be of strategic importance and a perfect fit with our radiation therapy instrumentation activities.*

### RPC-PET

Positron emission tomography, or PET, is an extremely sensitive technique of medical diagnosis. A marker containing a radioactive substance is injected in the patient's body, releasing positrons by radioactive decay in the zone to study. When the positrons encounter electrons from neighboring molecules, they annihilate, producing two very energetic gamma photons traveling in opposite directions. These photons are identified by a ring of detectors, to create detailed images of the organism and to monitor dynamic processes. The detectors, electronics and algorithms for image reconstruction used in PET are similar to those developed by particle physicists for their experiments.

RPCs, with their good uniformity, excellent spatial and time resolution and low cost per unit area, offer a radically different alternative to the usual crystal-based gamma detection systems, and a dramatic increase in the field of view. This line of work has been pursued by the RPC experts at LIP for a number of years. A high-resolution, small animal RPC-PET scanner developed at LIP is installed at ICNAS since 2014. Hundreds of tests have been performed on mice, with goals such as studying the molecular mechanisms underlying degenerative diseases or testing new drugs that may be used to treat certain diseases. Due to its excellent spatial resolution, this technology has the potential to be applied in human brain PET, changing the paradigm in the diagnosis and investigation of diseases of the central nervous system, and to play an important role in the characterization of vascular injuries. This will be a major line of work for the next few years.

### Orthogonal ray imaging

This is LIP's core project in instrumentation for radiation therapy, and is developed in partnership with two Portuguese oncology institutes, the Hospital of the University of Coimbra (CHUC) and several medical research centers. The aim is to improve radiotherapy by optimizing the treatment in near real time, so that the irradiation can better accommodate the tumor and spare surrounding healthy tissue. To do this, we make use of x- or gamma-rays emitted orthogonally to the treatment beam. The OR Imaging technique may be divided into two main branches: OrthoCT (orthogonal computer tomography) for monitoring radiotherapy (high-energy x-rays); and O-PGI (orthogonal prompt-gamma imaging) for monitoring proton therapy. In 2018, the LIP team pursued these two lines of research. In OrthoCT, 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.

As for O-PGI studies, a multi-leaf collimator has been fully optimized using Geant4 simulation and our own reconstruction routines. The optimization was based on the analysis of images obtained after the irradiation of the NCAT phantom (cardiac-torso anthropomorphic phantom) with realistic, therapeutic proton beams. Three scenarios were considered: an irradiation of the head of the patient with and without nasal cavities filling; an irradiation of the region of the pituitary gland for three different brain densities (mimicking the possible presence of edema formation); and a pelvic irradiation with patient mis-positioning (as could be caused, for example. by patient weight change). The most difficult scenario was the irradiation of the pituitary gland. Here, edematous tissue may account for a Bragg peak shift as small as 2 mm, which the O-PGI system was able to discriminate clearly. Work is now ongoing in order to devise an optimum crystal granularity 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 pediatric total body irradiation will also be analyzed via Monte Carlo simulations.

## Gamma cameras and position reconstruction in medical imaging

The group was formed in 2013 to apply the know-how accumulated at 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 clinical gamma cameras of classical design, and also to 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.

2018 new developments included work on the 3D calibration of thick scintillation crystals, in collaboration with the Radiation Detectors and Applications Group at Politecnico di Milano. Previously, the Monte Carlo simulation 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 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 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.

A portable gamma camera provides additional information to physicians that may result in improved outcome of sentinel lymph node 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 usage in thyroid imaging when not employed in surgery. We are determined to build and test the prototype in 2019 in collaboration with CHUC.

## Dosimetry

LIP has a long term expertise in dosimetry. From accelerator simulation to dosimeter prototyping, the work in the field goes back more than 20 years. This expertise can now be directed to exploit new developments in proton therapy. 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. Over the last years the number of facilities dedicated to proton therapy has increased in Europe. The possibility of the installation of a proton therapy facility in Lisbon opens a window of opportunity for research in this area.

The group follows two main lines of research: clinical dosimetry and High-LET (linear energy transfer) radiation microdosimetry. The first line focuses on the application of plastic scintillators and optical fibers in the context of clinical dosimetry for particle therapy. The second line focuses on the development of radiation detectors able to measure energy deposition at sub-mm scales and studies of radiation effects at cellular level, aiming at determining the biological efficiency and induced damage of high-LET radiation.

In 2018, the group developed and tested, in collaboration with the Nu-Rise company in Aveiro, 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 interventional cardiology under fluoroscopy. The first hospital tests will take place in 2019 in Hospital de Santa Maria, Lisboa. In addition, a microdosimeter was designed allowing for the determination of tracks and energy at the cell scale (which are stochastic in nature). We are also studying the potential use for microdosimetry of technologies based in plastic scintillators and silicon detectors, with high spatial resolution.

SELECTED
## References

"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

"Plastic scintillation detectors for dose monitoring in digital breast tomosynthesis", J. Antunes, J. Machado, L. Peralta, N. Matela, Nucl. Instrum. Methods Phys. Res. Sect. AAccel. 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

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: "Design and characterization of the readout ASIC for the BESIII CGEM detector", PoS TWEPP-17 (2018) 044

Ricardo Bugalho et al.: "Experimental results with TOFPET2 ASIC for time-of-flight applications", Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 912 (2018) 195-198

// CONTACTS

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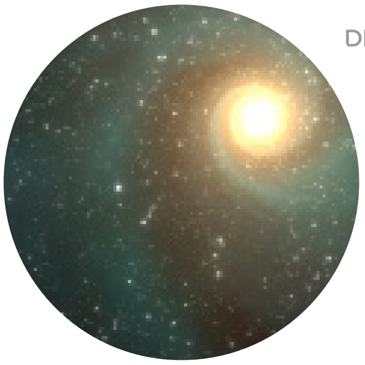

DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

# Space applications

## Into outer space

*Space exploration is a natural area of application of particle physics technologies, especially in what concerns radiation detection instrumentation and the modeling of complex processes involving the interaction of radiation with matter. Over the last decades, LIP became a recognized partner in the space community. LIP is today a partner of the European Space Agency (ESA) in several planetary missions and consortia for the development of scientific instruments. Important decisions in some of them are expected in 2019. The recent creation of the new Portuguese Space Agency is certainly boost activity in Portugal, both in academia and in industry.*

### Space Rad: Radiation environments and more

In the last 15 years an R&D line focused on the study of space radiation environments and their effects was created and consolidated at LIP. The competences developed include all the areas and technologies identified on ESA's roadmap for this domain, and LIP is the academic reference in these areas: radiation environment analysis and modeling; radiation effects analysis tools; radiation measurement technologies; radiation hardness assurance of Electrical, Electronic and Electro-mechanical components (EEE). In its activities, mostly developed under contracts with ESA, LIP works with different entities, both from academia and industry.

In 2018, the group was involved in the development of the RADiation hard Electron Monitor (RADEM) for the JUICE ESA mission to the Jovian system, with launch foreseen to 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 from Norway.

LIP has also been collaborating with EFACEC and EVOLEO in three different contracts regarding the AlphaSAT radiation Environment and Effects Facility (AEEF). AlphaSAT is the largest ESA telecom satellite, in geostationary orbit (GEO) since July 2013. LIP is responsible for the analysis of the in-flight MFS data, the AEEF particle spectrometer and radiation monitor and also of the CTTB, the AEEF Component Technology Test Bed, where EEE components are being tested in GEO radiation environment. LIP was also involved in the ground testing and preparation of the CTTB data analysis prior to the AlphaSat launch. 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. dMEREM is currently being upgraded and validated with data from Mars Curiosity Rover radiation detector (RAD). We are also working on its use in assessing radiation hazards in future manned missions to Mars and for astrobiology studies.

### i-Astro: astrophysics instrumentation in Space

The i-Astro group holds high-level competences in instrumentation for astrophysics, particularly in x- and gamma-ray polarimetry. It 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's 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 at the University of Ferrara. We contributed 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 out. The project aims to characterize the effects of the proton radiation environment on CdTe-based instruments in the context of a Low-Earth Orbit (LEO) mission.

// CONTACTS

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SELECTED
## References

"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

"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)

# Computing

Computer science is a fundamental tool in modern research. LIP develops novel information technologies and operates advanced services to support demanding scientific applications. As an example the LHC experiments have to process about 8000 Terabytes of data per year that must be analyzed by researchers in many different locations. A worldwide distributed computing infrastructure was developed to overcome this challenge.

LIP participates in some of the largest European R&D projects in this field and operates the largest scientific computing facility in Portugal. The facility is part of the Worldwide LHC Computing Grid (WLCG) and delivers computing and storage capacity to high energy physics experiments and to the research community in a large ensemble of scientific domains. In partnership with FCCN and LNEC, LIP leads the National Distributed computing Infrastructure (INCD), which is part of the Portuguese Science Foundation Roadmap of Research Infrastructures of strategic relevance.

# Computing

## Enabling Compute Intensive and Data Intensive Science

*Scientific research requires increasingly higher data storage and processing capacities that stress the limits of information systems and related technologies. Large scientific endeavors such as the LHC are perfect examples of this. The LHC distributed data simulation, processing and analysis led to the creation of the Worldwide LHC Computing Grid (WLCG), the largest distributed computing infrastructure ever built for a single scientific problem. The LIP distributed computing and digital infrastructure activities encompass the support for scientific research, through the provisioning of computing services, complemented by a component of innovation aimed at staying at the forefront of computing technologies, namely through a strong participation in some of the main European R&D projects in the field.*

### Distributed computing and digital infrastructures

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 research at LIP. 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's competences and capabilities is also backed by participation in R&D projects at national and international level. The group currently 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 (HPC).

In 2018 the Tier-2 has delivered 68,274,317 normalized (HEPSPEC06) processing hours to ATLAS and CMS. 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. A large fraction of the acquired capacity was temporarily added to the Tier-2 to perform the validation and acceptance of the hardware. 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 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.

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.

LIP, in the context of the INCD and IBERGRID activities, has organized the 2018 edition of the international conference on Digital Infrastructures for Research (DI4R). The conference joined EGI, Géant, PRACE, EUDAT and OpenAIRE and counted more than 400 participants. In parallel, LIP also organized the 2018 edition of the IBERGRID conference co-located with DI4R.

## Advanced Computing

The group, part of LIP-Minho since the beginning of 2014, has been directing its activity to the fields of Computer Science and Engineering more closely related to the main research areas of LIP. Its members have previous work in Grid, HPC, computing models, high performance communication libraries and distributed data structures. Research also encompasses R&D on the combination of traditional multicore CPUs with acceleration devices.

Particularly noteworthy are the support to the development and optimization of code applications related to particle physics and the search for explicit distribution strategies for access to large volumes of data, in order to improve efficiency and execution times. More recently the group embraced new topics related to the areas of big data and machine learning. Another important dimension of activity is the support to advanced training in Scientific Computing. The group is also responsible for the administration of a local HPC cluster that supports the running of the data analysis applications developed by other groups at LIP and a CPU/GPU system dedicated to machine learning and simulation.

SELECTED
## References

"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.2017.0 4.002

"Enabling rootless Linux Containers in multiuser 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

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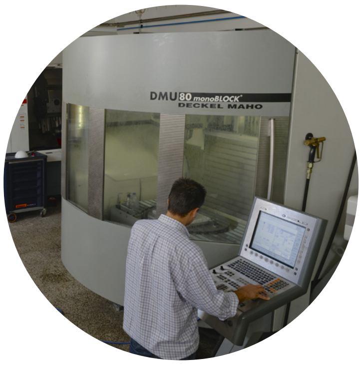
# Research facilities

- Mechanical workshop
- Detectors laboratory
- e-CRLab
- LOMaC
- TagusLIP laboratory






## Mechanical Workshop

The Mechanical Workshop (MW) of LIP was established in 1986, to support the experimental activities performed in collaboration with CERN. At present, the available equipment and the highly qualified staff allow us to perform a large spectrum of mechanical services, from project to production and testing. Today, the MW provides services to research groups inside and outside LIP and to external companies. The work developed by the MW is complemented by the Detectors Lab, as many of the projects at LIP need the competences of both facilities. Over three decades, the two infrastructures assured excellent quality support to detector R&D, as well as to the participation and responsibilities of LIP in large collaborations.

2018 has been a year with many projects and 100% of the time occupied. These included the construction, assembling and test of the second unit of the Umbilical Retrieval Mechanism (URM) for the calibration system of the SNO+ experiment; the construction of parts for the MARTA RPC detectors for the Pierre Auger Observatory, namely gas bubblers, gas connectors, electronic supports, HV PS boxes and auxiliary mechanical parts; the construction of the mechanics for a second RPC pre-clinical PET scanner; the construction of mechanical supports for the LZ group. Parts and pieces for many other groups were produced, namely for DL, LATTES, Gamma Cameras, SHiP, Gaseous Detectors R&D, HADES, RPC R&D, i-Astro, ATLAS, as well as the Physics Department of the University of Coimbra, and the Portuguese Oncology Institute. Further work was developed for LIP outreach projects.

// CONTACTS

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# Detectors Laboratory

The Detectors Laboratory (DL) was created at LIP's foundation with the aim of supporting the experimental activities developed at LIP. The laboratory has been continuously updated according to the general and specific needs of the research groups. The available equipment and technical staff allow a variety of services, including the design, construction and repair of electronic circuits and vacuum systems, and the design, construction and testing of particle detectors.

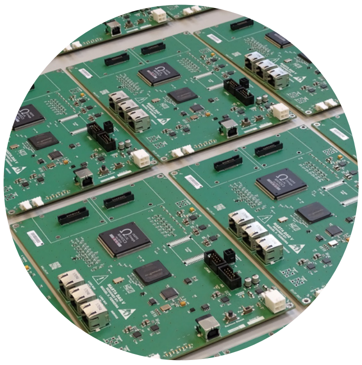
In 2018, the main activities were related to the R&D and production of three different types of large area RPCs used in international projects in which LIP is involved: MARTA, HADES and the TRISTAN cosmic ray telescope traveling to Antarctica aboard the Sarmiento de Gamboa scientific vessel. Our contribution is multidisciplinary and spans from project design to the installation and maintenance of the detectors, development of tools and instruments to control/monitor the detector performance, and adapting the detector to the individual requirements of each application, following procedures that are similar to industry's. In total during 2018 were build more than 80 $m^2$ of RPCs. The first prototypes of a sealed RPC were built and successively improved. We expect to produce the first detector in 2019. A fundamental activity of the DL is to assist the groups in their R&D activities. We contributed with technical work and added value in the following projects: animal PET, SNO+, LZ (system upgrade), HADES, AIDA2020, SINE2020, OrthoCT and muTT/Tomuvol. The DL had a major role in LIP outreach projects, namely the LIP spark chamber and the LIP cloud chamber, and developed work for the Physics and Chemistry departments of the University of Coimbra. A share of the work that is increasing is the one coming from direct contract for the provision of services and products by the DL to external clients, returning already considerable income.

# TagusLIP Laboratory

The TagusLIP Laboratory is a LIP research infrastructure installed in 2004 at the Lisbon Science and Technology Park. TagusLIP was conceived as a generic infrastructure for the development of radiation detectors with emphasis on nuclear medicine imaging technologies opened to external entities. 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 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 group Spinoff Technologies for Cancer Detection (STCD) developed long experience in the design and implementation of detector readout ASICs. 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.

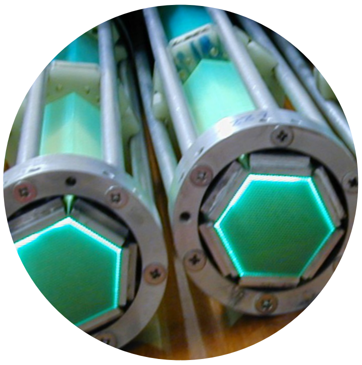
In 2018 the main users of the TagusLIP Laboratory were the LIP research groups and the startup company PETsys Electronics. On the LIP side, one of the main activities was the specification and system simulation of a new ASIC for the CMS MIP Timing Detector, in the frame of the Phase II Upgrade of the CMS experiment for HL-LHC. Particular attention was given to the impact of radiation on the SiPM performance and dark noise. The study of filtering algorithms capable of reducing the impact of dark noise on the timing resolution was undertaken. Concerning medical technologies R&D, a PET detector module with depth of interaction (DOI) and timing capability for large PET scanners was developed.



# e-CRLab
## (Cosmic rays electronics laboratory)

The e-CRLab is mainly dedicated to the development of electronics for cosmic ray experiments. The focus is put on fast digital electronics implemented in FPGAs. The laboratory has the capability to design complex printed circuit boards and to produce simple printed circuit board (PCB) prototypes. The production of complex PCB and its assembly is outsourced. There is capability to do rework in PCB boards. A small set of mechanical tools allows the production of simple detector prototypes mainly for proofs of concept.

In 2018, the e-CRLab gave 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 whenever needed, and shipped to Brazil for assembly. The e-CRLab also had the responsibility to design and produce support systems for MARTA such as the low voltage power supply unit, the Central Unit of the system, and the monitoring and control system of MARTA. 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 e-CRLab was responsible for the system integration of a muon hodoscope for muon tomography (starting from a gaseous voume fabricated at LIP-Coimbra) and has developed the support mechanics. The infrastructure has also developed work in 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. The e-CRLab also provided support for teaching and outreach activities, mainly by developing and maintaining experimental setups.



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# LOMaC
## (Laboratory of Optics and Scintillating Materials)

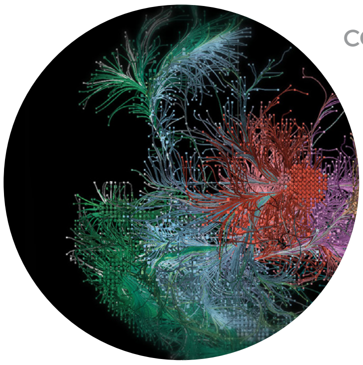
LOMaC's expertise is centered on the preparation and test of plastic WLS and scintillating optical fibres, scintillator plates and related devices to be used in high energy and nuclear physics detectors. LOMaC has facilities for cutting polishing and aluminizing (by magnetron sputtering) bundles of optical fibres; automated devices for the characterization and test of optical fibres, scintilators, and PMTs, and equipment to measure absolute light yield.

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. Along the years, LOMaC also selected and/or prepared optical fibres and scintillators for a number of international collaborations in which LIP had responsibilities, including DELPHI , SNO+ the ATLAS ALFA luminosity monitor, among others. It also gave crucial support to the development of the plastic profiles that house the WLS fibres in the TileCal calorimeter.

In 2018, a set of almost 3000 Kuraray Y11 WLS fibres was aluminized for the upgrade of the ATLAS TileCal gap/crack scintillators. 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 Mechanical Workshop in Coimbra. 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. LOMaC setups have been used in several educational and outreach activities, and LOMaC participated in the LIP Summer Internship program. In the medium term LOMaC contributions will focus in three areas: 1) the ATLAS TileCal and associated detectors; 2)studies for scintillator-based detectors for the Future Circular Collider. (using scintillators, WLS fibers and several photodetectors); 3) applications in microdosimetry, where characterization of scintillating optical fibres is foreseen, in close collaboration with the LIP Dosimetry Group.

# Competence Centres

Competence Centers at LIP are designed to be light and flexible horizontal structures joining all the LIP members that share the same tools and technologies. Such centers should have a positive impact both internally, increasing the synergies between groups, and externally, in advanced training and boosting LIP's collaboration with other research centers and with industry.



COMPETENCE CENTRES

# Simulation and Big Data

*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

In 2018, teaching of advanced detector simulation techniques as part of the curricula of specific undergraduate courses and doctoral programs was conducted, where the Geant4 toolkit is extensively used. In the context of one of these courses, a simulation tool for the description of virtual experiments for the teaching of Nuclear Physics laboratories, started to be developed. 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 were undertaken in the context of the activities of the LIP groups, and efforts towards a better integration of the activities will be pursued.

## Big Data

In 2018, the Big-Data branch of the competence center secured three funded projects in the big data area: FCT PTDC/FIS-PAR/29147/2017 BigDataHEP (started July 2018), COST action CA17137 (started September 2018) and STRONG-2020 (INFRAIA 01 Advanced Communities H2020 call, funding to start in 2019). The 1st School and Symposium "Data Science in (Astro)Particle Physics: the Bridge to Industry" was organized in Lisbon in March 2018. Furthermore, regular informal meetings are held among all the interested LIP members, which include topical discussions and tutorials, and collaborations in the context of machine learning are ongoing between members of different LIP groups: ATLAS, CMS, Auger, LATTES, Dark Matter, Phenomenology. In Minho, a collaboration with Bosch Car Multimedia in the context of the iSci-Bosch-ECUM project is ongoing.

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COMPETENCE CENTRES

# Monitoring and Control

*The Competence Center in Monitoring and Control (CCMC) is intended to 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. Also to facilitate the sharing of know-how and solutions in electronics and software design among LIP groups with the potential benefit of reducing development and delivery times and ensuring better debugging and quality control. A third goal is to establish partnerships/contracts with third parties (e.g. other laboratories, industry) where our scientific deliverables can be re-used.*

In 2018, the CCMC started the development of a complete software framework intended 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 main client was the ECOTOP group 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. One of the goals for 2019 is to organize a workshop on “Monitoring and Control for scientific and industrial applications”. 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.

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## Knowledge transfer and societal impact

## Advanced training

# SCIENCE AND SOCIETY

## Education, communication and outreach

## Radiation, health and environment

# Knowledge transfer and societal impact

*Fundamental science drives innovation in the long term. Particle physics technologies have a wide range of applications, and the potential to respond to societal changes. We aim at boosting our shorter term societal impact through specific research lines dedicated to applications to health care, space exploration and computing.*

## Technology transfer and industry

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 years, 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. 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.

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. 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.

In 2018, LIP had contracts or was in consortia with EFACEC SA, EVOLEO SA, PETsys Electronics, HYDRONAV SA, Nu-Rise, ICNAS-Produção, Cabelte and BOSCH. 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 2500 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) 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.

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 university and 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. The Monitoring and Control Competence Center is providing services do other research institutes at the University of Coimbra.

## 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. 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, Weizman Institute and Wigner Research Centre; which work across a range of world-leading scientific areas in the field of Particle Physics, Astrophysics and Nuclear Physics.

**http://heptech.web.cern.ch**

## Radiation, Health and Environment

Radon measurements are currently the focus of activity of LIP's Radiation, Health and environment group. 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. Knowing its concentrations inside houses is thus 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.

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.

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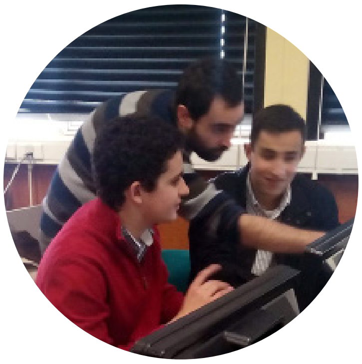

# Advanced training

*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 several levels (undergraduate, master, PhD).
Its goals are:

- To 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.
- To 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.

## Graduate students

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 8th IDPASC international School was held in Valencia, Spain, on 21–30 May 2018, the school included lectures, discussion sessions and a final exam. Over 20 students participated. The 4th IDPASC PhD Students Workshop was held. 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.

A major event was the 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.

The following events targeted at graduate and undergraduate students are foreseen in 2019:

**Particle physics mini-school**, Costa da Caparica, Feb 2019 - co-organized by LIP and CFTP.

**Data science school and symposium,** Braga, March 2019 - A flagship event emphasizing the connection to and partnership with industry.

**LHC physics course**, LIP-Lisboa, March to May 2019.

**IDPASC student workshop**, Braga, July 2019.

**IDPASC international school, Otranto,** Italy, May-June 2019.

**LIP Summer Student Programme,**
July-September 2019

In the framework of the 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.

## Undergraduate students

### LIP Summer Student 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. At the main target universities, there were sessions in which the different work proposals were presented.

**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.

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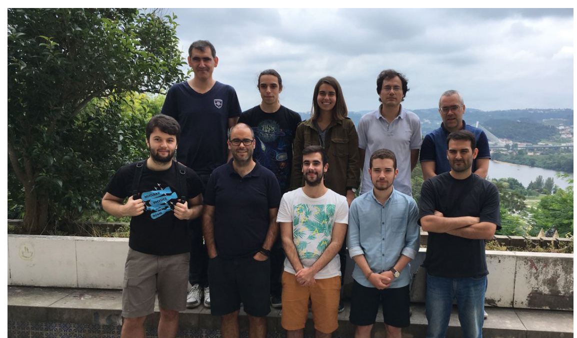
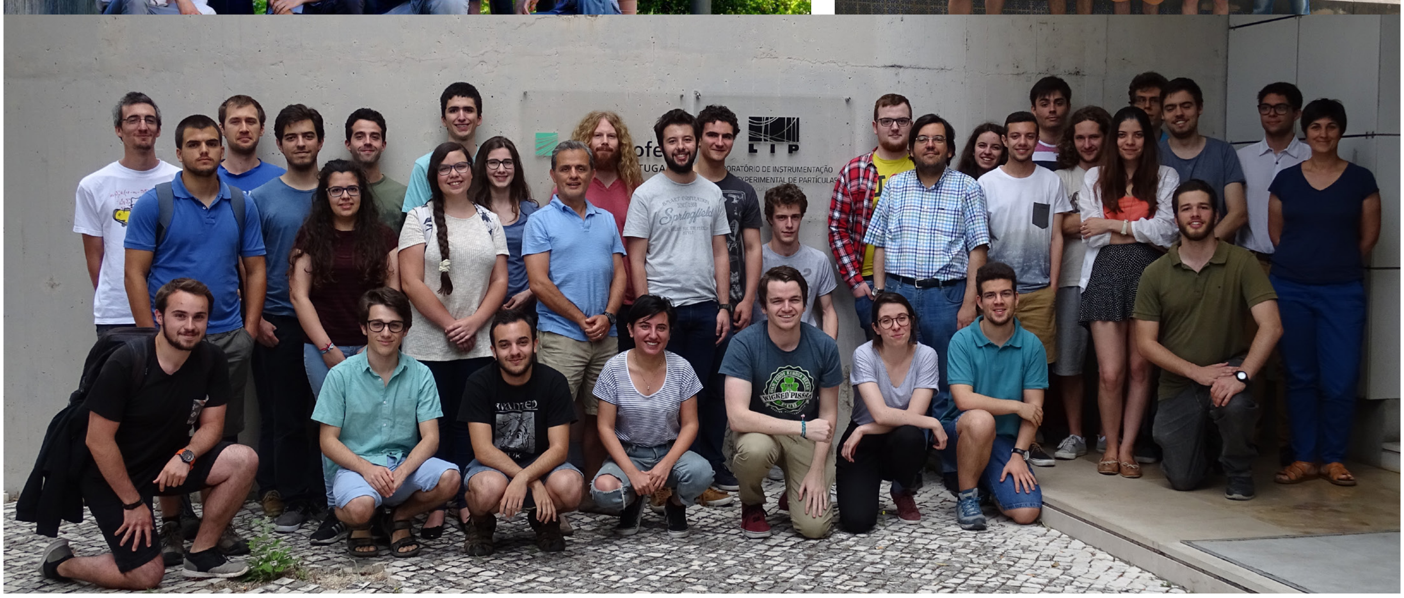
During 2018, Auger control shifts and, for the first time, CMS monitoring and data quality shifts took place. The CMS shifts were effectively used to train the students in the group, but also as opportunities to keep contact with the summer internship students and involve a wider group in the real monitoring 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.





# Education, communication and outreach

*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-ECO office, Education, Communication, Outreach and Advanced training

The LIP Education, Communication and Outreach group (LIP-ECO) was created in 2016 with the aim of better organizing and extending the ECO-related activities carried out at LIP. Priority target audiences were defined: our peers (universities, research centres and funding agencies); the LIP community (internal communications); undergraduate students in Physics and Engineering; the school community. Below we considerer two interrelated pillars of activity: institutional communications and education and outreach. The activities of LIP-ECO involve all three LIP nodes.

LIP has several national and international partners in communication, outreach, and support to education. At national level, we are partners of Agência Ciência Viva, the Portuguese Physics Society, and have a close collaboration with several schools. LIP is part of the International Particle Physics Outreach Group (now IPPOG collaboration), European Particle Physics Communication Network (EPPCN, which aims at fostering particle physics communication by maximizing information exchange between CERN and the Member States) and the CERN forum for high-school students and teacher programmes. During the last year, we highlight our participation in the preparation of the documents on communications and on education and outreach sent by EPPCN and IPPOG, respectively, as inputs to the ongoing update of the European Strategy for Particle Physics.

## 2018 highlights

### Project "SciCom with and for Students"

This project has the goal of involving LIP's PhD and master students in outreach activities and gave important steps forward in 2018. 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 feedback received 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 training in soft skills. Training in public speaking is offered to the participants.

### European Researchers Night

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".


## LIP flagship initiatives for the school community

### 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.

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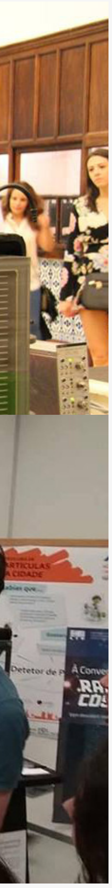

P2 ÍPSILON CULTO FUGAS P3 CINECARTAZ Entrar Assine já

CIÊNCIA › ESPAÇO MEDICINA ECOSFERA

FÍSICA DE PARTÍCULAS

**Bosão de Higgs visto (finalmente) a desintegrar-se em quarks *bottom***

Descoberta anunciada no Laboratório Europeu de Física de Partículas (CERN) é um passo fundamental para perceber como o bosão de Higgs faz com que as partículas fundamentais adquiram massa.

PÚBLICO - 28 de Agosto de 2018, 17:47

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### In the media

The publication in Público, a reference national daily newspaper, of articles related to LIP's research and based on our press releases: the observation of the Higgs boson decay to bottom quarks; Higgs boson production with a top quark (the LIP group in ATLAS works in both these analyses); recent multi-messenger astronomy results, published by collaborations in which LIP is not directly involved, but clearly related to our present and future projects, namely Auger and LATTES.

### The LIP-EduLab

It is a goal of LIP to go further in the support to education activities, creating the conditions to propose more laboratory-oriented activities. 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.

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
*partículas e tecnologia*

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