LIP

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

// ANNUAL REPORT 2016

Editors:
Catarina Espírito Santo
Ricardo Gonçalo

Design:
Carlos Manuel

CONTENTS

// ABOUT LIP

Introducing LIP

LIP is the reference laboratory for research in experimental particle physics and related technologies in Portugal. It exists for the discovery o the fundamental laws of the Universe.

What is dark matter made of? How many Higgs bosons exist and what are their properties? What was the Universe like just after the Big Bang? Where do the highest energy cosmic particles come from? Is the neutrino its own antiparticle?

These are some of the challenging questions currently addressed at LIP. Fundamental science drives innovation in the long term, and particle physics is at the forefront of technology. LIP is a key player in the application of particle physics technologies to Health and Space exploration and in scientific computing.

We aim to inspire the younger generations to pursue careers in science and technology, through international collaboration, excellence in research and training, and opportunities for engaging with society.

LIP is committed to research and development in experimental particle physics, new instruments and methods, and scientific computing. The laboratory is nation wide, with nodes in Lisboa Coimbra and Braga, in close collaboration with the local Universities. It has close to 200 members. LIP is the reference partner of CERN in Portugal. The Laboratory is also a partner of ESA and of other international scientific infrastructures, such as the GSI research center in Germany, the Sudbury Neutrino Observatory in Canada, the Pierre Auger Observatory in Argentina or the Sanford Underground Research Facility in the USA.

LIP is deeply involved in the LHC endeavor, participating in the ATLAS and CMS experiments from the very beginning, but also in other particle and astroparticle physics experiments, namely the COMPASS experiment at CERN and the HADES experiment at GSI, and in astroparticle experiments, detecting the particles that come to us from the cosmos — studying the origin and nature of cosmic rays in AMS and Auger; investigating neutrinos in SNO+ and NEXT, searching for dark matter deep underground with the LUX/LZ detector.

LIP conceives and builds the particle detection instruments of the future, to be used in fundamental experiments but also in applications to Health and Space exploration — for example in medical imaging devices, radiation based therapies, dosimetry, radiation environment studies and astrophysics instrumentation.

Computer science is a fundamental tool in modern research. LIP develops novel technologies to operate advanced services and support demanding scientific applications. The lab is part of several international projects on distribute computing technologies, including Grid, Cloud, high throughput and high performance computing. In partnership with FCCN and LNEC, LIP leads the INCD - Infraestrutura Nacional de Computação Distribuída.

Advanced training, support to education in science and technology and public engagement with science are central for LIP. LIP hosts several tens of graduate students going through a truly international training program in the framework of international collaborations and PhD networks. LIP offers summer internships and other training opportunities to undergraduate students.

LIP has a set of scientific infrastructures and competence centres that provide support to its research groups, and offer high quality services to the community. These include the precision mechanical workshop and detectors lab in Coimbra; the cosmic rays electronics lab, laboratory of optics and scintillating materials and TagusLIP medical imaging technologies lab in Lisboa; plus the simulation and big data competence centre. The Lab further aims to foster the links between technology and industry.

The associates of LIP are the Portuguese Foundation for Science and Technology (FCT), 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).

Directorates Report

prof.
Mário Pimenta
Directorates President

In the last 30 years LIP was able to develop its mission in terms of fundamental science, R&D in detectors and instrumentation and in education and public outreach. We started, under the guidance and vision of Mariano Gago and Armando Policarpo, as a small group (one dozen) of enthusiastic and curious young PhDs. Today we are a lively community of nearly 200 researchers, engineers, technicians, and graduate students supported by just 7 dedicated administrative staff. LIP is now a national organization, with delegations at Lisboa, Coimbra and Braga. LIP associates were, at the start, just the Portuguese funding agencies (nowadays FCT) but, later, Coimbra, Lisbon and Minho Universities, Instituto Superior Técnico and ANIMEE join as well. In 2016, we had the joy of welcoming the Faculty of Sciences of the Lisbon University as LIP associate.

CERN was and will be our main reference. We were created to develop and support the scientific and technical participation of Portugal at CERN. Nowadays LIP has groups at the LHC (ATLAS and CMS) as well as in the fixed target program (COMPASS and several R&D projects) and it is fully engaged in the preparation of the high Luminosity LHC upgrade program. The challenges and the opportunities of this program are enormous, from apparently "minor" problems, such as the electrical resistivity of cables in the aggressive LHC environment, to the need for processing huge quantities of data. The involvement of industry is mandatory and, in coordination with FCT, LIP is engaged to boost the participation of the Portuguese industry in the upgrade activities. Last year, our phenomenology activities at the LHC were reinforced and enlarged by the adhesion of the "Heavy Ion Phenomenology" group focused on the exploration of the Quark-Gluon plasma produced in heavy ion collisions.

Astroparticle and non-accelerator particle physics are fast-growing scientific domains, with already many medium and even large size international experiments and observatories. LIP is an active player in the areas of cosmic rays (Pierre Auger Observatory and AMS), searches for dark matter (LUX/LZ) and neutrino oscillations, and double-beta decay (SNO+ and NEXT). The stable operation of autonomous RPCs during the last two years in the hostile environment of the Argentinian pampa, as well as the production of the mechanics for the complex SNO+ calibration systems, were clearly important technical landmarks.

Space missions, instrumentation for nuclear physics and medical physics are strategic application areas. Our groups in these areas profit from the existing scientific and technical know-how at LIP to develop target activities. The participation in ESA programs started already several years ago. The group has steadily grown and is already the Portuguese reference for space radiation and environment studies. A collaboration with CTN (Sacavém) in the irradiation of electronic components and in the test and calibration of detector prototypes has been successfully pursued, and hopefully will be enlarged in the near future. The development of detectors for experiments at GSI, Darmstadt, in Germany, was a major technical achievement by LIP. The RPC-TOF detector developed for HADES is probably the detector of this kind with the best performance in the world. At present, the focus is on the development of new detectors in view of the future Facility for Antiproton and Ion Research (FAIR). The precise framework of the Portuguese participation in FAIR has however to be established. LIP has several on-going projects in the fields of medical imaging and radiotherapy instrumentation. Collaboration with hospitals and health research institutes is crucial in this aspect, and we should stress the close collaboration established with ICNAS in Coimbra.

Computing and Research Infrastructures are key elements at LIP. The recent approval of the funding proposal for the National Infrastructure of Distributing Computing, created through the initiative of LIP, ensures a stable working framework for the next few years. An intense participation in the European programs will continue to be a priority.

The management and the working conditions of the LIP research infrastructures were reviewed to improve their capability to answer to internal and external requests. In this direction, the idea of "Competence Centers" is making its way at LIP. They should be light and flexible horizontal structures, joining all LIP members that share the same technical expertise and tools. Such centers should have a positive impact both internally, increasing the synergies between groups, and externally, either in advanced education or boosting LIP's collaboration with other research centers and with industry. The first one, on "Simulation and Big Data", is in preparation and should come into operation during 2017.

Education, communication, outreach and advanced training are integral parts of our mission. The intense and fruitful, but sometime disperse, activities that we developed in the past years will henceforth be pursued in a coordinated way, by the newly created ECO (Education, Communication, Outreach) office and by the Advanced Education Group. ECO action has already made the difference for instance, on the organization of the LIP public report and of the exhibition commemorating the LIP 30th anniversary. A roadmap for LIP's communications activities, as well as an annual plan of the advanced training program will be established starting already this year. An internal Workshop joining all PhD students of LIP will be held every two years. The first of these Workshops was held already recently in Coimbra. The PhD networks DAEPHYS and IDPASC, coordinated by LIP, have been a powerful instrument both for ensuring a PhD grant program in our field and to promote formative activities (the seventh annual two-weeks-long IDPASC school will be held this year, in June, at Asiago, Italy). At this moment, it is not clear what will be the support that we can expect from FCT for these programs in following years.

New premises for LIP in Lisbon, doubling the present area and allowing for the first-time to have appropriated conditions for research and teaching laboratories, were contracted with the Lisbon University. They will be inaugurated on the 9th May, the day of LIP's 31st anniversary. From July on we will be all, in Lisbon, in the new premises. In Coimbra, the University made available a new area for the expansion of the mechanical workshop and of the detectors laboratory. And in Braga, the University announced that a new area for LIP-Minho will be available soon. Finally, a "control room" for remote CMS and Auger shifts will be installed at IST, in Lisbon. We believe this will be an useful tool to introduce students to the environment of experimental particle and astroparticle physics.

Scientific employment is the major issue for the development, even the survival of Portuguese science at a competitive level, and LIP is not isolated. The number of permanent positions for the scientists with an age below 50 is rather scarce while the mean age at the Universities Physics Departments is unusually high (for instance at IST this mean is 55.6 years!) The good news is that the new Portuguese authorities have not only recognized this critical problem, but are promoting an aggressive program to replace the endless post-doc grants by contracts. Most of these new contracts will however be at fixed-term. An increase of the long-term positions, namely at the Universities, must happen to guarantee the future. LIP will try, by all possible ways, to be part of the solution.

Research funding is always smaller than existing needs. In 2016, and probably in 2017, the public (FCT) funding for science was basically kept at a constant level. We hope that an increase should happen in the next years following the evaluation of all research centres to be carried by FCT during this year. In any scenario, the effort to find complementary National or European funding is at the top of LIP's priorities.

The challenges that we will have to face are not small by any means. Nevertheless, we are confident that we will be able to face them with ambition and competence.

(Mário Pimenta - President of LIP)

Report from the International Advisory Board

L. Rolandi, S. Bertolucci, K. Parodi, C.W. Fabjan, P.G. Innocenti, M. Teshima

The LIP International Advisory Committee met at the University of Minho in Braga on 28 and 29 April 2017.

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.

One mission of LIP is the study of the fundamental laws of particle physics. This research is carried out at the CERN LHC (ATLAS and CMS experiments) and at the CERN SPS (Compass). The origin of cosmic rays and the astrophysics implications are studied with ambitious programs, with a large array of earth-based detectors (Auger in Argentina) and on the International Space Station (AMS). The search for the possible constituents of Dark Matter in our Universe is pursued with LUX and the follow-up experiment LZ (in USA) and the nature of neutrinos is investigated with SNO+ in Canada. This research, addressing some of the most fundamental and topical issues in particle and astroparticle physics, is conducted in large international
scientific collaborations to which LIP makes essential contributions of world-class quality.
LIP has a long tradition of world class development of new instruments and methods for particle physics, for example, in the area of Resistive Plate Chambers. These competences are very effectively directed to another mission of LIP, applying these particle physics technologies to areas of benefit to Society. One example is LIP's ambitious program of advanced medical imaging instrumentation for diagnostics and therapy , which is very promising and could make a major impact if the prototypes under development would eventually reach clinical use. LIP contributes also in significant ways to important programs in terrestrial and space radiation monitoring.

LIP has been spearheading the employment of large computing resources needed for particle physics. This program has been very successful, leading most recently to the establishment of the National Infrastructure for Distributed Computing (INCD), which serves and benefits not only LIP but also all of the Portuguese scientific community.

LIP has always been a champion in communicating its research activities to the public. During the past year, it has reached a new level of professionalism by developing a broad communication strategy and establishing the "LIP-ECO" program (Education, Communication, Outreach).

One further positive development is the long awaited move of LIP Lisbon to new premises on the University Campus. It will provide better working conditions for the scientists, closer ties with the University and consolidation of the technical infrastructure.

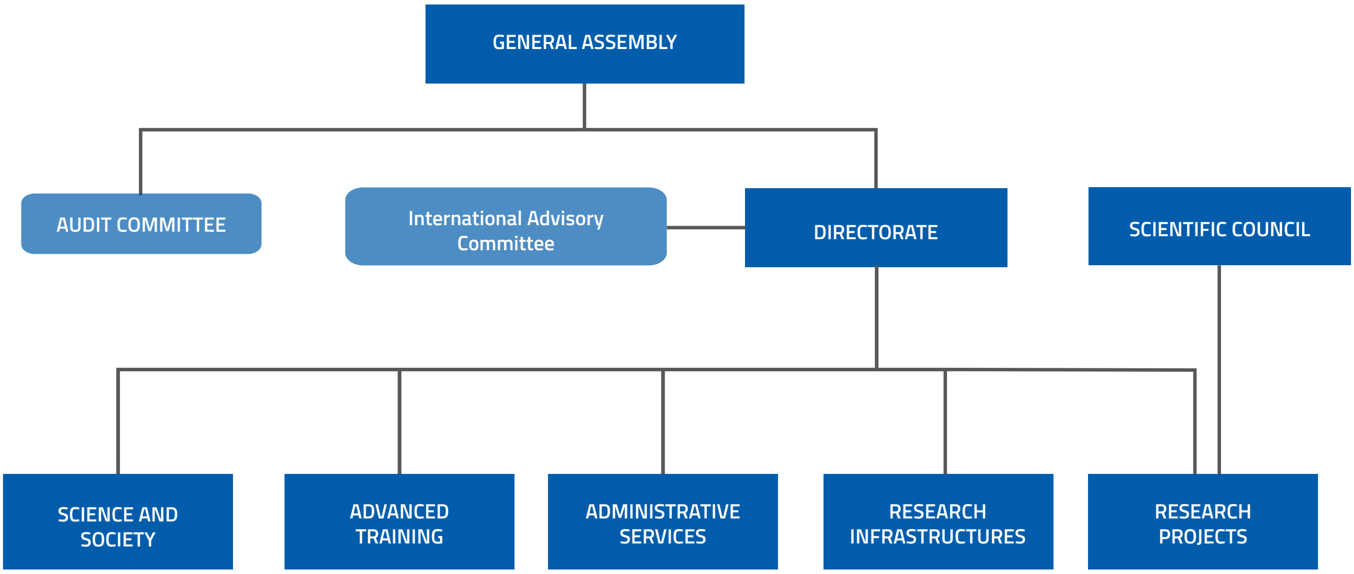
Given LIP's growth and evolution over the past thirty years it became important to review and to adapt the governance structure of the Laboratory. This process has been successfully concluded during the past year.

The Committee was very pleased to learn that new positions were established in the form of joint appointments between Universities and LIP. The Committee considers this a most effective way to foster research and education with mutual benefit to both parties.

The Committee was again impressed by the careful use of the rather limited financial and personnel resources with which a very broad and multi-faceted program is carried out with remarkable success. LIP is in the process of establishing "Competence Centers", an important move to further increase efficiency and impact of the Laboratory. Aligning the funding strategy more closely to the scientific research plans of the Laboratory will arguably also result in more effective usage of the funds, a step the Committee recommends to consider.

The Committee congratulates the LIP directorate and the LIP staff for another exceptionally productive year and
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. It is designed to be efficient and flexible.

In accordance with its statutes, LIP is governed by a Board of Directors nominated by its General Assembly, after consultation of LIP members, according to the by-laws. LIP's Scientific council is the lab's scientific management body. Its members are all PhD holders, the heads of LIP's research facilities and a representative of the students from each LIP node.

An External Advisory Committee, holding regular meetings with Directors and group leaders, provides strategic advice to the Laboratory. LIP administrative and financial operations are systematically audited by external auditors and reviewed by a top level independent finances council and auditing authority.

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. The scientific council has ordinary meetings four times per year and extraordinary meetings whenever necessary. Once every two years, a lab meeting takes place. In these "Jornadas científicas" the scientific work of all groups is presented and discussed. Group leaders are encouraged to foster the participation of younger and senior members, and of students. LIP Student's workshops have recently been established. In these meetings, all PhD students present the status of their work to the LIP community.

General Assembly

- Fundação para a Ciência e Tecnologia (Presidente)
- Universidade de Coimbra
- Universidade de Lisboa
- Universidade do Minho
- Instituto Superior Técnico
- Faculdade de Ciências da Universidade de Lisboa
- ANIMEE

National directorate

President: Mário Pimenta

Directors: Gaspar Barreira, Rui Marques, Paulo Fonte, António Onofre

Node directorates

Lisboa: Mário Pimenta, Gaspar Barreira

Coimbra: Rui Marques, Paulo Fonte

Minho: António Onofre, Nuno Castro

Scientific council secretaries

Patrícia Gonçalves, Filipe Veloso

International advisory board

Christian W. Fabjan, Katia Parodi, Luigi Rolandi, Masahiro Teshima, Pier Giorgio Innocenti, Sergio Bertollucci

Finance council

António Morão Dias, João Ferreira do Amaral, Vera Martins, José Martins Correia, Maria Salete Leite

Highlights of the year

LIP's general scientific meeting "Jornadas do LIP", January 2016

INCD - Infraestrutura Nacional de Computação Distribuída, led by LIP in partnership with FCT and LNE, is part of the National Roadmap of Research Infrastructures of Strategic Relevance

IPPOG's International Masterclasses in Particle Physics in Portugal, February-March 2016

The exhibition "Partículas: do bosão de Higgs à matéria escura" celebrated the 30th anniversary of LIP in Braga, Coimbra and Lisboa. February-May 2016

An exceptional year for the LHC: From April to December, the accelerator delivered a record amount of data to its experiments

Proton spectrometers at the LHC: The CT-PPS used non-final detectors to collect 15.2 fb−1 of data integrated in the CMS data set. ATLAS installed one arm of the AFP experiment and took data in special low-luminosity runs. Summer 2016

Summer internships bring close to 40 undergraduate students to LIP

The Auger upgrade AugerPrime was approved and featured as cover story in the June 2016 CERN Courier

The LUX Collaboration announced new world-leading results: exclusion limits on dark matter. July 2016

Visit to Portugal of Art MacDonald, Nobel Prize for Physics 2015, particularly to LIP's workshop in Coimbra, where equipment for the SNO+ calibration is being produced, September

LIP and the University of Lisboa signed the contracted for the new LIP premises in the 3Is building of ULisboa.September 2016

ATLAS outstanding Achievements Awards given to ATLAS LIP members, October 2016

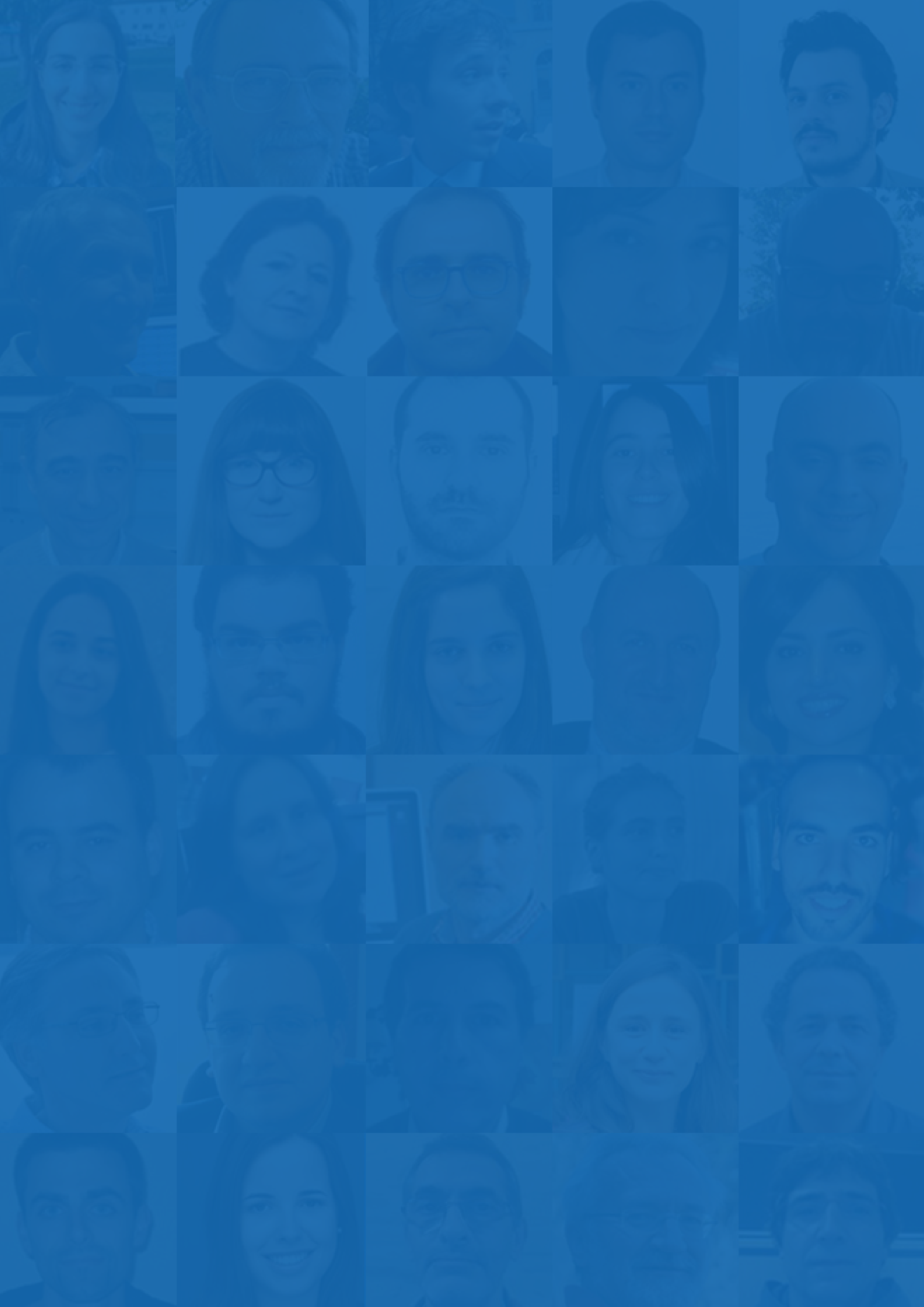
FCUL - Faculdade de Ciências da Universidade de Lisboa officially joined as LIP Associate, November 2016

LIP's achievements on RPC-based neutron detectors highlighted within SINE2020 and in physics.org, November 2016

5 years of AMS data presented at CERN by S. Ting, with intriguing result on the positron spectrum. December 2016

Another year of Drell-Yan data taking in 2018 approved by the CERN SPS Committee, December

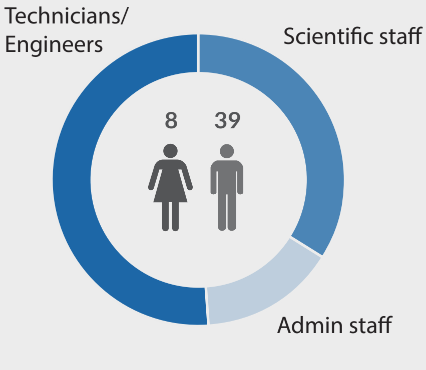
URM shipped to SNOLAB - Umbilical retrieval Mechanism for the SNO+ calibration system was built at the LIP workshop in Coimbra, December



// LIP IN NUMBERS

HUMAN RESOURCES

STAFF



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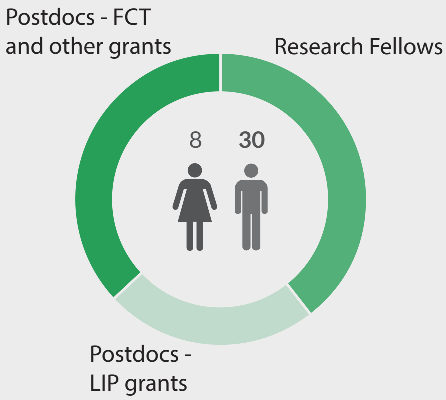
47
TOTAL

Technicians/ Engineers	0	24
Scientific staff	3	13
Admin staff	5	2

FIXED-TERM RESEARCHERS



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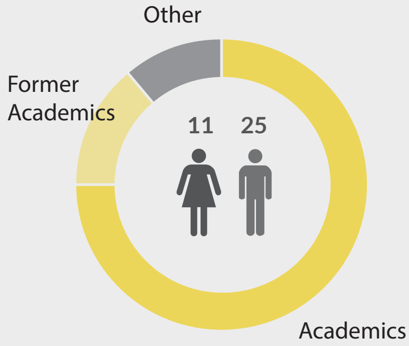
38
TOTAL

Postdocs FCT and other grants	2	12
Research Fellows	5	10
Postdocs LIP grants	1	8

UNPAID



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36
TOTAL

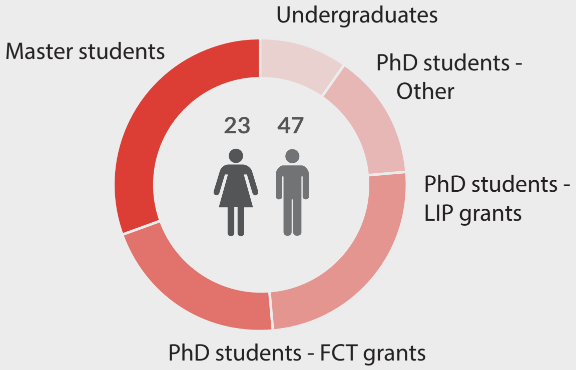
Academics	5	22
Former Academics	4	1
Other	2	2

TOTAL

191

50 141

STUDENTS



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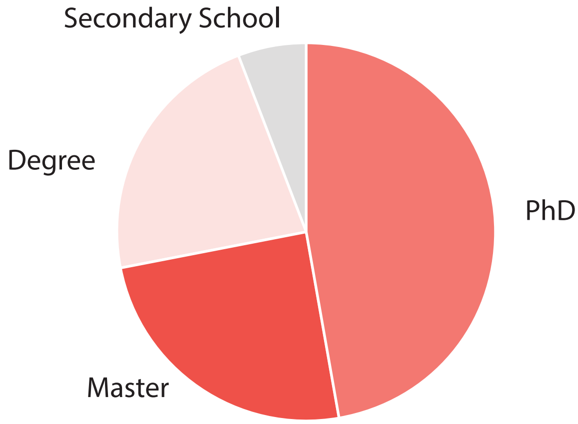
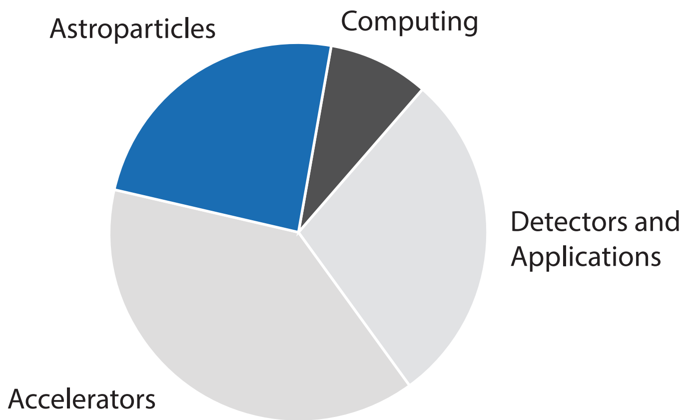
70
TOTAL

	Women	Men
Master students	8	14
PhD students FCT grants	1	14
PhD students LIP grants	8	10
PhD students Other	3	5
Undergraduates	3	4

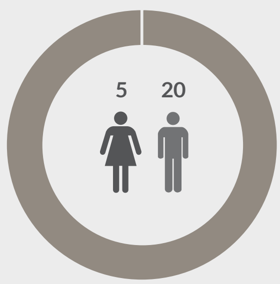
DISTRIBUTION BY ACADEMIC DEGREE



DISTRIBUTION BY RESEARCH AREA



EXTERNAL COLLABORATORS



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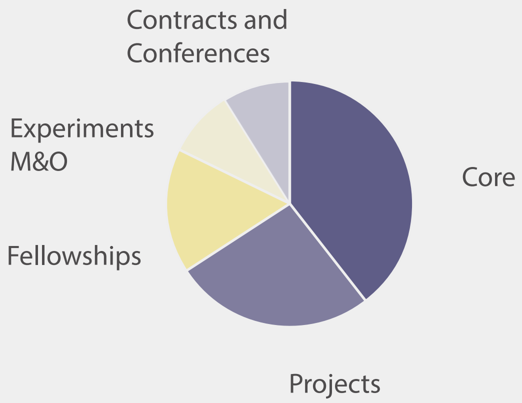
25

TOTAL

GENERAL FUNDING



1.8M
CORE FUNDING

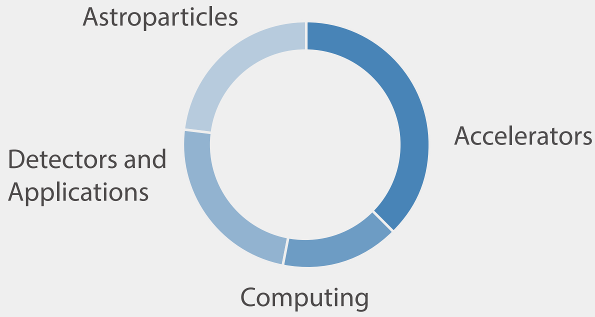
1.2M
PROJECT-BASED

0.75M
FELLOWSHIPS

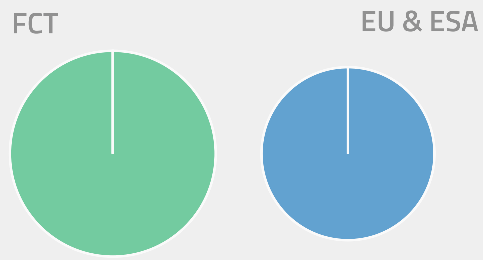
0.4M
EXPERIMENTS M&O

0.4M
CONTRACTS AND CONFERENCES

PROJECT-BASED FUNDING BY RESEARCH AREA



FUNDING BY ORIGIN

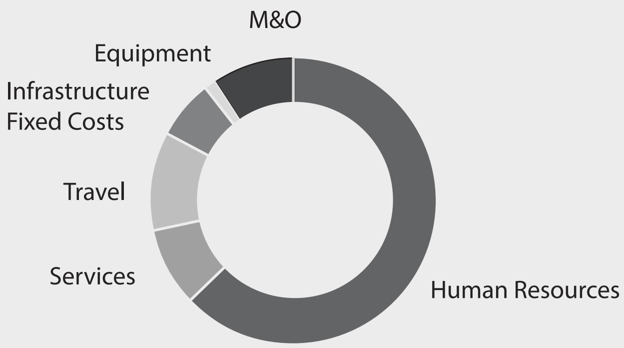


TOTAL
1.2M €

TOTAL
4.6M €

FINANCES

COSTS



HUMAN RESOURCES

STAFF 1.5M

FIXED-TERM RESEARCHERS 1.3M

SERVICES AND OTHER EXPENSES

0.4M

TRAVEL

0.5M

EXPERIMENTS M&O

0.4M

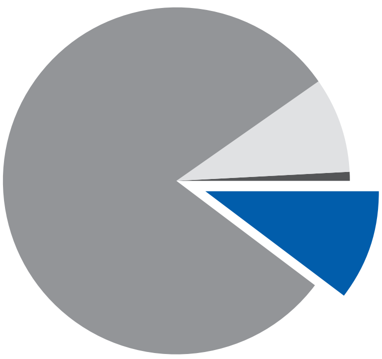
INFRASTRUCTURE FIXED COSTS

0.3M

EQUIPMENT

0.06M

SCIENTIFIC OUTPUT

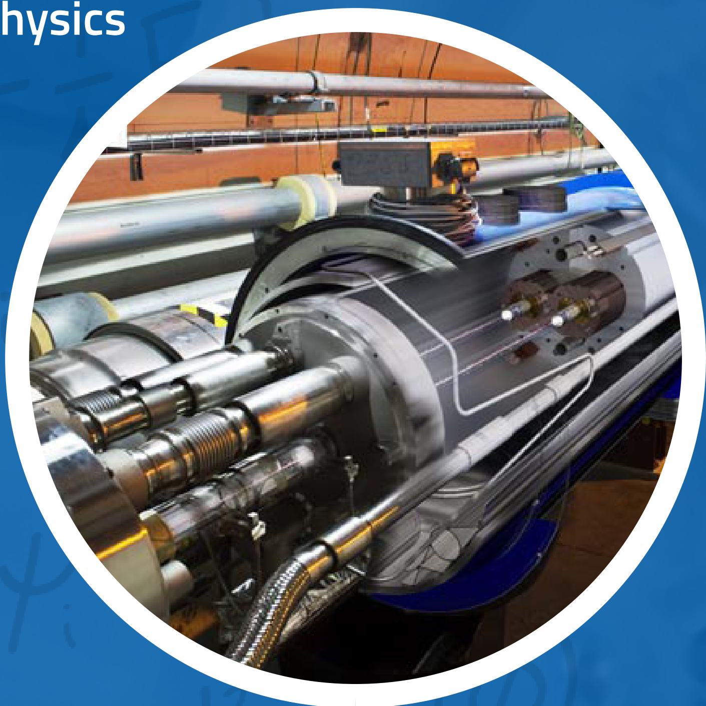
		Astroparticles	Accelerators
Books, Reports and Proposals		1	0
PhD Theses		0	4
Master Theses		3	6
Proceedings		4	20
Notes		13	15
Presentations		32	49
Papers in refereed journals		25	193

Detectors and Applications	Computing	TOTAL
0	3	4
1	0	5
8	0	17
15	1	40
5	4	37
22	7	110
21	2	241

Astroparticles Accelerators Detectors and Applications Computing

// RESEARCH

Experimental particle and **astroparticle physics**



Developme **new instru** and **method**

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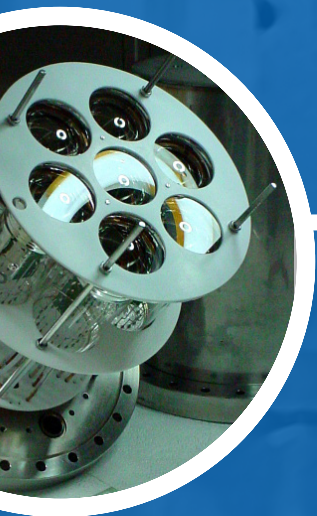
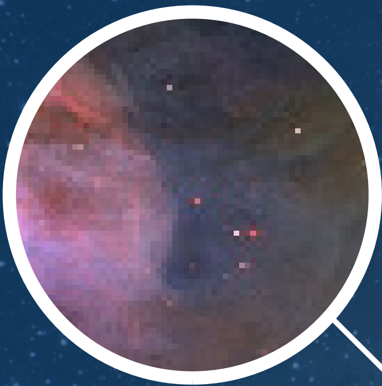
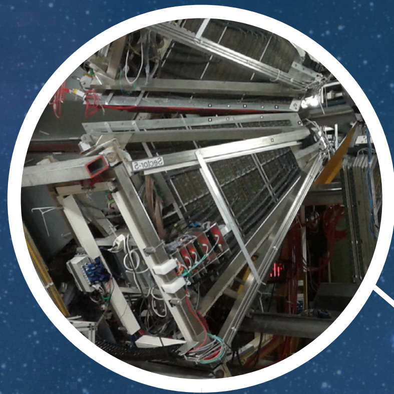


Computing

RESE



Experimental particle and astroparticle physics



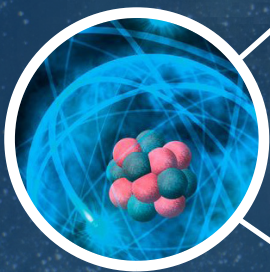
Development of new instruments and methods

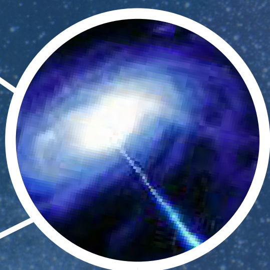
LHC experiments and phenomenology

- ATLAS
- CMS
- LHC phenomenology
- HIP

Structure of matter

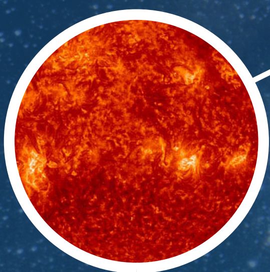
- COMPASS
- HADES





Cosmic rays

- AMS
- Auger
- LATTES



Dark matter and neutrinos

- LUX/LZ
- SNO+
- NEXT

ARCH

Computing

- GRID
- Advanced Computing

Detectors for particle and nuclear physics

- Neutron detectors
- RPC R&D
- Liquid Xenon R&D
- NUC-RIA

Health and biomedical applications

- RPC-PET
- OR Imaging
- Gamma Cameras
- STCD TagusLIP

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 do this in an optimal way LIP's LHC phenomenology and heavy ions physics groups create strong links between experimental and theoretical particle physics. At the same time, we are very actively improving our experiments, to respond to the 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, The LIP structure of matter group is currently involved in the COMPASS experiment, designed to study hadron structure, and in the HADES experiment at GSI, studying cold nuclear matter at high densities.

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 deeply involved in these challenges through its engagement in the Auger, AMS, LATTES, LUX/LZ , SNO+ and NEXT collaborations.

EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

LHC experiments and phenomenology

Physics at the energy frontier

In 2016 the LHC performed exceptionally well, delivering a record amount of data to its experiments and going above its design specifications. In fact, it routinely broke new records of number of collisions, or luminosity, every few weeks. This allowed many physics analyses to be performed or updated with more data, literally leading to hundreds of new papers by the LHC experiments in which LIP collaborates, and to many theory and phenomenology results.

The LIP ATLAS and CMS groups were active operating their experiments and analyzing the new collision data to produce exciting new results. In addition, both experiments have installed new proton detectors near the beampipe, a few hundred metres from the main experiments, which allow windows into previously inaccessible diffractive physics. Finally, they have spent much effort on the R&D and planning necessary for the LHC and experiments upgrade programme. The upgrade phase 1 will take place from 2021 to 2024 and will be followed by the High-Luminosity LHC phase, starting in 2026 with the final aim of collecting some 3000 fb^{-1} per experiment. The centre of mass energy will stay at a similar value, up to 14 TeV, but the increasing rate of events will pose serious challenges to the experiments and their data treatment infrastructures. A new phenomenology group, HIP, has joined our laboratory with an exciting physics programme. Their interest in heavy ion physics will be a great complement to our experimental activities in this area. The LHC Phenomenology group kept its activity focused on top quark and Higgs sectors.

One particular issue led to intense scientific debate throughout most of the year, even if it did not produce a discovery: the unraveling of the 750 GeV di-photon excess. In December 2015, a noticeable excess of events was seen, in both the ATLAS and CMS experiments, in collision events containing two high-energy photons. This type of event had previously produced evidence for the Higgs boson, with a mass of around 125 GeV. But the new, unexpected signal indicated a possible new particle at a mass of 750 GeV. By early January this had given rise to more than 150 theory papers proposing new physics models to explain the observation. The experimental updates with more data from ATLAS and CMS were eagerly awaited. Finally, at the ICHEP'16 conference in August, it became clear that the apparent excess was, in fact, a statistical fluctuation. The mystery had been dispelled, but the exercise had taken the theory community to explore previously untouched ground and concoct new ideas. And once a new idea is born, it often finds its use in unsuspected places. The future will tell.

A heavy trio – the Higgs, the W, and the top quark

The Higgs boson was observed by the ATLAS and CMS experiments in 2012 and is, so far, the most important discovery made at the LHC. More than being the last missing piece of the Standard Model (SM), the central place occupied by the Higgs in our understanding of fundamental physics makes it a new window into Nature. The ATLAS and CMS groups at LIP have been active in exploring the properties of the new particle, its couplings, and the possibility that other Higgs bosons exist, which could give precious hints on the nature of new physics we know is out there.

The focus of the ATLAS team is on measuring the properties of the Higgs boson, and especially its couplings to bottom and top quarks, which are still very poorly known. These properties are accessible through measurements of the Higgs boson in associated production with a weak gauge boson (WH or ZH) and with a pair of top quarks (ttH), with the Higgs decaying to b quarks in both cases. The group has been contributing to both these channels within the ATLAS collaboration. The highlight of the group's contributions to the challenging WH and ZH analysis [1] was the identification of sensitive discriminant variables, to be used in a multivariate analysis, that increased the experimental sensitivity by around 7%. The group has also been contributing to the Higgs search in ttH production, through dedicated studies of specific sources of background affecting this analysis.

A collaboration that was initiated in previous years between the LHC phenomenology and the ATLAS groups at LIP continued to pursue the investigation of angular variables in ttH production. This investigation has already led to a paper in the past, where variables sensitive to the Higgs spin were proven to enhance the significance of the ttH→ttbb signal with respect to the main irreducible background, ttbb, where the b-quark pair is produced from the splitting of a spin-1 gluon. Several new variables were identified during the past year, which provide experimental sensitivity for probing the CP nature of the top-Higgs coupling. The conclusions will soon be documented in a paper currently in preparation.

The CMS team has also been paving the way for future experimental studies of di-Higgs production, with studies to evaluate the use of machine-learning techniques for the reconstruction of this very challenging channel. Di-Higgs production is the ultimate goal of the LHC Higgs programme, and will eventually provide experimental sensitivity to the Higgs self-coupling, which directly probes the structure of the Higgs potential. Touching the areas of Higgs, supersymmetry, and top-quark physics, the group has also contributed to the final publication of the search for a charged Higgs in LHC run-1 data [2]. The continuation of this analysis for run 2 is starting, with the measurement of the top-pair production at the new centre of mass energy of 13 TeV, in events containing tau leptons originating from the top quark decays. Besides the intrinsic physics interest of this channel, it is also a crucial source of background in the search for a charged Higgs boson.

The ATLAS team has a long-standing tradition of searches for Flavour Changing Neutral Currents (FCNC) decays of the top quark. An observation of this process, forbidden at leading order in the SM, would give strong indications on the nature of new physics beyond the SM. An article describing the search for top quark decays ($t\rightarrow qZ$) via FCNC in top pair production at 8 TeV was submitted in late 2015 and published in the beginning of the year [3].
No evidence for signal was found and a 95% confidence level upper limit on the branching ratio was established: BR($t\rightarrow qZ$)<7x10-4. This analysis has since been updated with 13 TeV data from the LHC run 2, and a new publication is expected in mid 2017. Other measurements in the area of top-quark physics are proceeding in the group, such as a measurement of the top quark decays to a W and an s quark. This is a sub-dominant decay of the top quark that can provide a direct measurement of the |Vts| element of the Cabibbo-Kobayashi-Maskawa matrix, which describes flavor-changing weak interactions.

The CMS group made a leading contribution to a search for exclusive $\gamma\gamma\rightarrow W^+W^-$ production using LHC run 1 data [4]. The colliding, quasi-real photons are emitted by protons from the beam, which may remain intact or dissociate into unobserved products. This channel is sensitive to possible anomalous quartic gauge couplings, which would indicate the presence of new physics beyond the SM. The present analysis resulted in a 3.4 σ evidence for this process, with a measured cross section in agreement with the SM within the experimental uncertainty. Using a discriminating variable from this analysis (di-lepton transverse momentum), the team could establish limits to several anomalous quartic--coupling parameters, limiting the parameter region where new physics may be found.

Seriously seeking SUSY

The supersymmetric extensions of the SM, or SUSY, provide natural candidates for new physics, whose existence is heralded by e.g. astrophysical measurements of the mysterious dark matter and dark energy. The search for signs of supersymmetric particles is one of the focus of the CMS team at LIP. In 2016, several analyses of LHC run-1 data were concluded and published, probing several possible SUSY scenarios.

The team contributed to the search [5] for the stop1, the lighter of the two supersymmetric partners of the top quark, in CMS data collected in 2012. This search targeted final states where the stop decays include the lightest chargino (χ^0) and neutralino ($\chi^\pm$) predicted by the model, and allowed to determine new lower limits for the masses of the stop1 (700 GeV) and χ^0 (250 GeV).

Another paper exploring supersymmetric final states in a compressed mass spectrum scenario was published [6]. In this case, events with soft leptons, low jet multiplicity, and missing transverse momentum were targeted. The search used data collected in 2012 and established a lower limit on the top squark mass of 316 GeV, at 95% confidence level. This assumes a stop at least 25 GeV more massive than the lightest supersymmetric particle, and a 100% branching ratio for its 4-body decay into a b quark, fermions and a neutralino. The group is also involved in the continuation of this analysis using LHC run 2 data.

The CMS team is also involved in the search for stau and chargino pair production in di-tau final states, notably in the development of new background estimation methods, which were the object of an internal note. This analysis was written up and submitted to the JHEP journal for publication, and the object of a PhD thesis.

Exotic new physics

The ATLAS team has been developing a strong expertise in searches for new, heavy vector-like quarks. Vector-like quarks are hypothetical particles whose existence would be tightly connected with the electroweak symmetry breaking and the Higgs mechanism. They would account for the unexpectedly low value of the Higgs mass, one of the lingering mysteries in this area.

The team has contributed to two papers published in 2016 [7,8] and is currently making a leading contribution to the first ATLAS search for the Z/t+X topology using LHC run-2 data. The search focused on the final state containing two charged leptons, electrons or muons. First results were produced, still within the collaboration, and the analysis is currently in progress. Another focus of the team is the definition of the strategy for combining the statistical power of different vector-like quark search channels.

The group is also coordinating an analysis of top quark production accompanied by large missing transverse momentum. This channel is interesting since it can be sensitive to the elusive dark matter particles, in addition to vector-like quarks. First internal results were produced using LHC run-2 data and the analysis is proceeding.

Finally, a member of the ATLAS team contributed to a new tool [9] to be used for interpreting experimental measurements in the context of effective field theories. This provides a practical model that includes basic predictions of the theory and can be used to capture the main features of the experimental measurements even if the details of the underlying theory may be unknown. Effective field theories avoid the need for a fully worked out theoretical model, as in the case of Fermi's explanation of beta radioactive decay as a point-like interaction, which was successful decades before the W boson was identified as the true origin of this decay.

A needle in a haystack – rare decays

One of the physics highlights in 2015 was the joint observation by the CMS and LHCb collaborations of the extremely rare decays $B^0_s \to \mu+\mu-$ and $B^0 \to \mu+\mu-$, with a strong contribution from the CMS group at LIP. The branching ratios in these decays are very sensitive to the existence and nature of new physics beyond the SM. In 2016, the group has actively explored LHC run-2 data, developing strategies to address the dominant sources of systematic uncertainty with a view to update this important analysis.

The team is also involved in the search for the lepton-flavour violating decay of the tau lepton into three muons. This decay is forbidden in the SM, and its observation would therefore be a clear sign of new physics. The group has explored the decay kinematics and contributed to the development of a dedicated trigger algorithm, which is essential in extracting this extremely rare process from the flood of collisions produced in the experiment.

The hot Universe – hadronic matter and heavy-ion collisions

Apart from its proton-proton programme, the LHC is a unique place to study heavy-ion collisions. Part of every year is reserved for colliding lead ions, Pb-Pb or p-Pb, at the highest energies ever achieved in laboratory conditions. This already led to one of the physics highlights of the LHC, when its experiments have confirmed the existence of the quark-gluon plasma.

Hadronic jets in very energetic heavy ion collisions signal the presence of quarks, which cross the quark-gluon plasma medium, and so are invaluable probes for its study. The ATLAS team is deeply involved in these studies, focusing especially on the use of jets initiated by heavy b quarks to probe the dense quark-gluon plasma. The group is making a solid contribution to the analysis, and has developed a common tool to clean jets from instrumental background using multivariate methods.

The CMS team has a long history of studies of heavy quarkonium production. The team contributed to the measurement of the polarization of Υ(1S), Υ(2S) and Υ(3S) mesons versus the charged particle multiplicity using data collected in 2011 [10].

The CMS group is also involved in the study of the polarization of χ_c and χ_b states. This is a much more challenging analysis than the Υ(nS), but largely simplified by a methodology developed within group. Finally, the CMS team is also contributing to the study of heavy-flavour production in proton-proton collisions, since these results serve as reference to corresponding studies in Pb-Pb collisions.

On the Heavy-Ion Phenomenology side, the HIP group joined LIP and started in the best possible way. In 2016, the group successfully achieved the inclusion of new physics effects (transverse momentum broadening and medium back-reaction) into the existing hybrid strong/weak coupling model that describes the interactions of hadronic jets in the quark-gluon plasma. The team has included effects such as jet recoils against an electroweak boson in the dedicated JEWEL event generator, and produced several papers documenting this [e.g. 11]. Other work was in the direction of applying jet substructure techniques to jets in heavy-ion collisions, and is documented in two papers currently in preparation.

Tools of the trade – Detector operation and upgrade

In addition to the physics analysis activity during 2016, the ATLAS and CMS teams at LIP were very actively involved in operating their experiments to efficiently record the collisions produced by the LHC. This involves an enormous volume and variety of tasks: from detector operations to data quality monitoring, updating event reconstruction algorithms, trigger conditions or the detector control software to react to new demanding conditions caused by the increased collision rate, studying the performance and stability of detector calibrations [12,13], etc.

The CMS team is a long-standing contributor to the electromagnetic calorimeter (ECAL) data acquisition system and trigger, and has made leading contributions to its operation and upgrade in the last year. It installed and commissioned new optical serial link boards (oSLB) that interface the ECAL electronics to the trigger system. This was done in time to start detector operation in early 2016. On the ATLAS side, some of the main operational areas were on the hadronic calorimeter (TileCal) operation, including the detector control system, and on jet trigger operations.

In parallel, both groups are also investing an increasing fraction of their effort in preparing for the future. The LHC will be upgraded in two phases, one to start operation in 2021 with around twice the current luminosity. A second phase, known as High-Luminosity LHC, will start around 2026 with even higher luminosity, with the goal of collecting around a factor 50 more data by the end of the LHC operation than has been collected so far.

The ATLAS team is involved in the upgrade of the TileCal calorimeter. This is one of the main ATLAS subdetectors, where the group holds important responsabilities. In 2016, the ATLAS team has designed new electronics boards for the high-voltage distribution system of the TileCal, and initiated an R&D effort directed at scintillators and wavelength-shifting optical fibres, with a view to replace some parts of the detector which have suffered radiation-induced aging. Another group responsibility is on the hadronic jet high-level trigger algorithms. Here, the higher event rate expected after the LHC upgrade means that a solution to speed up the calorimeter processing must be found. The group has developed a parallelized version of the more time-consuming algorithm to run in general-purpose graphical processors (GPGPU) as part of a demonstrator in collaboration with other groups. This demonstrator is now in the evaluation phase.
Finally, the ATLAS and CMS teams were responsible for the ope-

ration of the Portuguese Federated Tier2 in the Iberian Cloud, which delivered a capacity in excess of expectations, with very good reliability and availability metrics.

New detectors to explore new ground

Both CMS and ATLAS have new proton spectrometers installed close to the beam, a few hundred metres to either side of the main experiments. These detectors allow windows into previously inaccessible physics and have already started producing exciting results. The CMS group at LIP is a leading contributor to the new CMS-TOTEM Precision Proton Spectrometer detector (CT-PPS) [14], which was already fully operational in 2016. The ATLAS group is a strong contributor to the ATLAS Forward Proton tagger (AFP), which had one arm installed on one side of the main ATLAS detector. The second arm and a dedicated Time-Of--Flight detector is currently being installed to operate in 2017.

Possible hints of an excess in di-photon events at 750GeV from CMS and ATLAS, announced at the end of 2015, gave a strong motivation to advance the CT-PPS installation. During the year, this detector could collect about ~40% of the total 2016 luminosity collected in CMS and has proven for the first time the feasibility of operating a near-beam proton spectrometer at high luminosity on a regular basis. The data collected in 2016 by the new detector is being used in a search for exclusive $\gamma\gamma \rightarrow l^+l^-$ production events in proton collisions, in which two charged leptons are reconstructed in the central CMS detector and are accompanied by the presence of un-dissociated protons detected in the CT-PPS detector.

The ATLAS team is involved in the AFP detector control system and in the AFP jet trigger, both in the study of the performance of the level-1 hardware trigger and in the design of specific triggers to select di-jet events in central exclusive production.

Prizes

This was an exceptional year for the ATLAS group, in which a member of the team, Filipe Martins, and a former member, Joana Miguéns, were distinguished with the ATLAS Outstanding Achievement Award, given to collaborators who made important contributions to the operation and development of the experiment. Joana Miguéns was furthermore awarded a second prize for her PhD thesis, on the Observation and measurement of the Higgs boson in the WW decay channel, developed at LIP and defended at the Faculdade de Ciências, Universidade de Lisboa in December 2015. But since all good things come in threes, members of the group also received a Best-poster Award for a paper on the TileCal detector control, presented at the CETC 2016 conference.

LIP is very proud of these awards, which testify to the quality of the work developed by our members.

Coordination positions

The ATLAS and CMS Collaborations have, each of them, more than 3500 members from about 200 institutes in 40 nations. The LIP groups presently have a number of coordination position in the structure of both Collaborations. In particular:

In CMS:
- CT-PPS Project Manager: João Varela;
- CT-PPS Timing Detector Coordinator: Michele Gallinaro;
- CT-PPS DAQ Coordinator: Jonathan Hollar;
- ECAL Electronics Coordinator: José Carlos Silva;
- Co-convener of the CMS B Physics and Quarkonia Analysis Group: Nuno Leonardo.

In ATLAS:
- TileCal DCS coordinator: Filipe Martins;
- Convener of the Heavy Quarks, Top and Composite Higgs subgroup: Nuno Castro;
- ATLAS physics office member: Nuno Castro;
- Iberian Cloud coordinator: Helmut Wolters;
- Monte Carlo manager for the Exotics Working Group: Juan Pedro Araque;

In addition, the groups participate in the following collaboration structures:

In CMS:
- CMS Executive, Management and Finance Boards: João Varela
- CMS Collaboration Board: João Varela and João Seixas
- CMS Physics Coordination: Nuno Leonardo
- ECAL Executive Board: José Carlos Silva
- ECAL and CTPPS Institution Boards: João Varela

In ATLAS:
- ATLAS National Physicist Board: Patricia Conde
- ATLAS Collaboration Board: Patricia Conde
- TileCal Institutes Board: Amélia Maio, Agostinho Gomes
- Trigger/DAQ Institutes Board: Patricia Conde
- Forward Detectors Board: Amélia Maio, Patricia Conde

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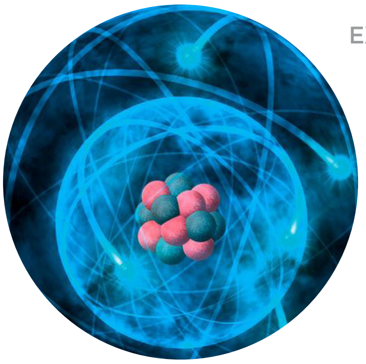
// CONTACTS

Patricia Conde (ATLAS), pconde@lip.pt
João Varela (CMS), joao.varela@cern.ch
António Onofre (LHC Phenomenology), Antonio.Onofre@cern.ch



EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

Structure of matter

Looking inside hadronic matter

Knowing the properties of the elementary particles and the way in which they interact is knowing what we are made of. The properties of quarks and gluons must determine the properties of protons and neutrons and, as a consequence, of the atoms themselves. And we still have a lot to discover about the ways in which elementary quarks and gluons work together to form the particles we observe, from the proton to a variety of more exotic hadrons. The LIP structure of matter group is currently involved in the COMPASS experiment, designed to study hadron structure, and in the HADES experiment at GSI, studying cold nuclear matter at high densities.

COMPASS – the workings of nucleons

Researchers at LIP study how quarks and gluons group together to form nucleons and other hadrons in the COMPASS experiment at CERN. 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 π meson beams with a fixed polarized target at a temperature of -273 °C, very close to the absolute zero, and observe the particles that result from these collisions. These experiments use beams from the SPS accelerator (super proton synchrotron). The target is followed by a two stage spectrometer: a first stage with a large angular acceptance, and downstream a second one with a reduced acceptance, designed to detect particles up to more than 100 GeV/c.

Keeping it under control — the Detector Control System

The LIP group is fully responsible for the Detector Control System (DCS). Over the years, the COMPASS DCS has continuously evolved, in order to accommodate the required complexity while promoting flexibility, reliability and speed.

In 2016, the DCS integrated new and refurbished COMPASS detectors, in view of the deep virtual Compton scattering long data taking run. The DCS system must be in operation practically 12 months per year.

A wealth of data to explore

The previous COMPASS programme, which lasted until 2011, focused on the measurement of the gluon polarization, of the longitudinal and the transverse quark spin structure, and of fragmentation functions. The LIP group strongly contributed to key data analysis subjects of this programme. In 2016, further results concerning these matters have been published [1,2,3]. New analysis methods were also developed, in order to increase the measurements' precision. Subjects addressed included detailed and refined studies of spin asymmetries, transversity and structure functions. Presently, the research follows two main lines of work: the Drell-Yan and the deep inelastic scattering programmes.

Learning from muons pairs — Drell-Yan studies

In the Drell-Yan process, a pair of leptons is created from the annihilation of a quark and an antiquark, in hadron-hadron collisions. The process provides valuable information on parton distribution functions — the sharing of the hadron momentum among its constituent quarks and gluons. In 2015, a COMPASS data taking period lasting several months was dedicated to Drell-Yan, following a pilot run in 2014. The LIP group and the Torino group developed and lead the polarized Drell-Yan experimental programme in COMPASS. During 2016, the LIP group coordinated the Drell-Yan data reconstruction and analysis. The full data sample was reconstructed in record time, and the analyses are ongoing.The polarized Drell-Yan process measurement is a world first. The results are expected to provide a crucial check of non-perturbative QCD: the sign change of the Sivers transverse momentum dependent parton distribution function of the nucleon, when accessed from Drell-Yan or from semi-inclusive deep inelastic scattering. The LIP group is leading this effort. In 2016, the CERN SPS Committee approved another year of Drell-Yan data taking in 2018. The LIP group is very well positioned to have a leading role in this.

The run must go on — the 2016 data taking

Deep inelastic scattering probes the inside of hadrons using high-energy leptons. In 2016, COMPASS devoted its data taking to the study of exclusive processes in deep inelastic scattering: the deeply virtual Compton scattering and the deeply virtual meson production. These measurements were done with a polarized muon beam on an unpolarized liquid hydrogen target. In parallel, the semi-inclusive deep inelastic scattering with unpolarized target was measured, with the goal ro measure the unidentified hadron multiplicities, as well as charged pion and kaon multiplicities. These provide crucial input for the determination of the quark fragmentation functions in an unexplored kinematic range. The LIP group is directly involved in these studies.

HADES – the secrets of high densities

The HADES high acceptance spectrometer at GSI is design to study cold nuclear matter at high densities [4,5]. It is a versatile detector for the precise spectroscopy of e+e- pairs (di-electrons) and charged hadrons produced in proton, pion and heavy ion induced reactions, in a 1-3.5 GeV/nucleon kinetic beam energy region. Di-electrons originating from in-medium hadron decays, and rare strange hadrons (kaons, hyperons), are the main probes measured in the experiment.

After several successful data taking campaigns, including the heavy system Au + Au run in 2012 and pion induced reactions in 2014, the accelerator infrastructure has been shut down for a complete upgrade. HADES will be one of the first experiments to be operational in the new infrastructure, with the mission of providing high-quality di-electron data at baryon densities and temperatures not accessible to other detectors, neither in the past nor in the foreseeable future.

Building and operating a flawless detector

The main contribution of the LIP team was the design and construction of a high granularity, high-resolution Time of Flight (TOF) wall, based on timing Resistive Plate Chambers (RPC). This new system reduced the limitations imposed on the spectrometer by the old scintillator-based TOF, that prevented HADES from doing measurements with heavy systems, a fundamental part of the physics program. The RPC-TOF wall (RPC-TOF-W) has been running within specifications and flawlessly during all campaigns. Most probably, it is the detector of this kind with best performance in the world. The LIP team has the responsibility of the RPC operation and optimization in HADES. Even during the current long shutdown, the detector was kept powered and running, due to its intrinsic characteristics. The team is also collaborating actively with the ECAL group on the installation of the new electromagnetic calorimeter of HADES, which will have a huge impact on the RPC detector since this will be supported on the ECAL frame.

In order to increase the acceptance of the spectrometer, a new detector covering very low polar angles in the forward region is being constructed. This forward wall is composed of a tracking detector and a TOF detector. The LIP group is in charge of the simulation, design and construction of the TOF detector for the forward wall, the RPC-TOF-FW.

In 2016, the choice of the specific RPC technology to be used was made, and the implementation of the RPC-TOF-FW into the simulation framework of the experiment has started. In 2017, this work will be completed and a first prototype module of the RPC-TOF-FW will be built and tested.

At FAIR, HADES will have to cope with higher beam intensities and energies, and high detection and tracking stability standards have to be maintained. The LIP group collaborates with the HADES multi-wire drift chambers group in this task.

In 2016, the stability of the tracking system with a new gas mixture was verified, chambers were repaired and spare chambers built. Investigations on a new design for prototype chambers construction is ongoing.

Data analysis – into the fireball

The LIP group is involved in the di-lepton analysis, and contributing with a new method of lepton identification based on a dynamic neural network. A preliminary di-lepton mass spectrum was extracted from the Au-Au data taking at 1.25 GeV/nucleon. The selection of leptons from a hadronic environment of up to 300 tracks/event was efficiently performed by the dynamic neural network.

To investigate the hadron properties within the dense medium produced in Au+Au collisions, all di-lepton contributions from elementary nucleon-nucleon collisions and from long-lived hadrons (decaying outside the fireball) must be subtracted. The resulting thermal spectrum will be used to determine the lifetime and temperature of the fireball. By comparing the thermal spectrum with model predictions, the in-medium modifications of the ρ_0 properties will be investigated, contributing to a better understanding of the mechanism responsible for mass generation in hadrons.

In parallel, the preparation of the 2018 and 2019 runs, with lighter nuclei systems and a slightly higher energy, will proceed with dedicated simulations and a close collaboration with a Portuguese theory group.

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// CONTACTS

Paula Bordalo (COMPASS), bordalo@lip.pt
Catarina Quintans(COMPASS), quintans@lip.pt
Alberto Blanco (HADES), alberto@coimbra.lip.pt

EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

Cosmic rays

Messenger 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.

AMS – a particle detector in Space

The AMS Spectrometer is installed in the International Space Station, orbiting the Earth since 2011. 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 [1]. LIP is part of this project from the start and contributed to the construction of AMS's RICH sub-detector, wich continues to be part of the group's responsibility. AMS remains a unique observatory in Space and is expected to continue taking data up to at least 2024.

RICH performance and reconstruction

The LIP group took part in the design, construction, simulation and data reconstruction algorithms development of the RICH detector. The RICH measures particle velocity and charge, and is fundamental for isotope separation and charge selection. Today, the group has responsibilities in its monitoring and operation, from the payload operation control center at CERN, and cares for the RICH-specific reconstruction performance monitoring and optimization.

An extremely rich data set

AMS's long exposure time and measurement precision, make its data ideal to fully characterize the Solar modulation phenomenon. The LIP team is involved in analyzing the time variability of proton, helium and electron fluxes at low energy and their interpretation under solar modulation models [2]. In 2016, a proton selection was developed, selection efficiencies were studied, the time-dependent detector efficiency was parameterized and a time-dependent proton flux was estimated.

The group is also involved in anti-proton/electron separation. Anti-protons are secondary particles and their study can provide us with information on dark matter annihilation in the Galaxy. The major backgrounds for anti-proton analysis come from electrons, that have the same charge and are about 100 times more abundant, and from wrong-sign reconstruction of protons. The group worked in the optimization of the anti-proton selection, based on the electromagnetic calorimeter signal. The LIP team conducted phenomenological studies of cosmic ray propagation, and is developing a statistical estimator for deuteron/proton separation based on the response of the different AMS sub-detectors.

Auger – the most energetic particles in the Universe

The Pierre Auger Observatory covers are area of 3000 km^2 in the pampa Amarilla, Argentina. It consists of 1600 detectors separated by 1.5 km that sample the shower 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.

New detectors in the pampa

In the last few years, LIP has been deeply involved in the development of autonomous, low gas flux, large surface RPCs for outdoor operation. More than 20 such detectors were produced at LIP-Coimbra and 6 are working successfully in Malargue [3]. The MARTA concept combines the Auger surface detectors with an RPC. A MARTA engineering array of 8 surface detectors (and 36 plane RPC) is under construction, in a close collaboration between LIP and Brazilian colleagues. It will be used to obtained a deeper understanding of the surface detectors, for the validation and in situ test of the scintillation detectors and for detailed shower studies at lower energies (10^{18} eV). In 2016, a dedicated test with a water Cherenkov detector and a RPC hodoscope was used to study the response to isolated muons. First data suggest no aging of the tank for ~10 years. Engineering prototypes of both HV and MARTA DAQ were produced. Suppliers and technical solutions were identified for the production of the enclosures in Brazil. Tests in the field showed a correct operation of the RPC detectors with stable efficiencies.

Particle physics with Auger

The LIP group is mainly focused on the full exploitation of the particle physics potential of the Observatory, namely on the efforts to understand hadron interactions at high energies through a window that is largely complementary to the LHC.

The observation of more muons in Auger than was is 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 hadron interaction modeling. The LIP group is directly involved in this quest [4,5].

In 2016, a method to interpret the measurement of the number of muons in extensive air showers, developed at LIP, was improved and published. The impact of changes to the muon energy spectrum (at production) on the measurements at ground was studied and also published. In addition, it was possible to assess the maximum and, for the first time ever, the fluctuation of the muon production depth distribution. This drastically enhances the capabilities to discern mass composition from new hadronic physics scenarios. Finally, the average longitudinal profile measurement was fully reviewed, and the framework for the measurement of the average lateral shape was set up.

LATTES – at the top of the mountains

The observations of gamma-ray telescopes in the last decade changed radically our perception of the Universe, raising new puzzles about the mechanisms powering the most energetic phenomena: gamma-ray bursts and relativistic outflows such as jets from black hole accretion disks or pulsar winds. High-intensity flares with an energy spectrum extending beyond the GeV have been observed. The next step will be led by instruments able to continuously survey large portions of the sky, and sensitive to the energy gap between satellites and ground arrays (50 GeV — 0.5 TeV). Present and planned large field-of-view (FoV) gamma-ray observatories are installed in the Northern Hemisphere, and miss in particular the galactic center. While a wide FoV Southern Hemisphere observatory will surely be proposed and built, the question is whether it will be similar to the existing extensive air shower (EAS) arrays, or an innovative solution able to cover this energy gap. The technological challenges of lowering the energy threshold of air shower arrays have been considered nearly impossible to overcome, as they stem directly from the physics of air showers.

Bringing RPCs to 5000 m

The goal of LATTES is to design, prototype and construct a a ground array able to monitor the Southern gamma-ray sky above 50 GeV, bringing to ground the wide field-of-view and large duty cycle observations characteristic of satellites, with comparable sensitivity and a cost one order of magnitude lower. Such an instrument will be a powerful time-variance explorer, able to issue pointing alerts to IACTs (Imaging Atmospheric Cherenkov Telescopes), boosting the efficiency of these powerful instruments, and thus fully complementary to the Cherenlov Telescope Array (CTA). It will collect abundant and highly relevant data, and play a fundamental role in the search for emissions from extended regions, such as the Fermi bubbles or dark matter annihilation regions. To overcome the huge technology issues involved, LATTES proposes an innovative concept: a compact EAS array of hybrid detector units, covering an area of at least 20,000 m^2, to be placed at high altitude (about 5,000 m above sea level, a.s.l.) in the Southern hemisphere. Each detector unit combines two autonomous RPCs, with good space and time resolution, with a water Cherenkov detector, ensuring trigger efficiency and efficient background rejection, and thus good sensitivity all the way down to 50 GeV [9].

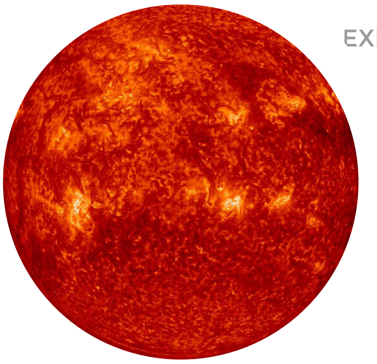
Paving the way

The proposed solution is conceptually and technologically innovative, and relies on well-grounded R&D in which LIP had a leading role. The LATTES concept has been proposed during 2016 by scientists from Portugal (LIP), Brazil (CBPF) and Italy (INFN-Padova and Roma). To pursue such an ambitious goal, a sound international collaboration must exist. The collaboration is taking form and should get the first dedicated fundings during 2017. Currently, the priority of the LATTES international team is to develop the concept in its different dimensions, bringing it in the next five years to the point in which it is mature for the construction of a full scale experiment. The process implies the completion of the detector R&D, the construction of two full-size prototype detector units and the construction of a 100 m^2 engineering array operating at 5000 m altitude. The LIP team is deeply involved in the project, with central responsibilities in the development of the simulation framework and performance evaluation, as well as in detector R&D. Efforts to build a strong collaboration, gain support within the community and attract funding are now crucial.

See selected references in page 36

// CONTACTS

Fernando Barão (AMS), barao@lip.pt
Pedro Assis (Auger), pedjor@lip.pt
Mário Pimenta (LATTES), pimenta@lip.pt



EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

Dark matter and neutrinos

Hunting for the most elusive particles

What do neutrinos and dark matter have in common? They are searched for in deep underground detectors that other particles can't reach. Only in such clean, background-free environments one can try to better understand the properties of the elusive neutrinos, which interact only through the weak force, or look for direct hints of the still undetected dark matter particles. In the coming generation of highly sensitive detectors, neutrinos also become a relevant background for dark matter searches. Through its engagement in the LUX/LZ, SNO+ and NEXT collaborations, LIP is deeply involved in the quest for dark matter and for a deeper understanding of neutrinos, two of the great challenges in particle physics for the next decades.

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. LIP is part of the LUX collaboration, operating the Large Underground Xenon detector, and a founding member of LUX-ZEPLIN (LZ), which will be the most sensitive dark matter experiment in the world.

LUX – a world leading result

In 2016, LUX completed the 332 live-days second science run, corresponding to an exposure of 3.35×10^4 kg.day. With roughly fourfold improvement in sensitivity for high WIMP masses relative to the previous LUX results (from 2015), this search yielded no evidence for WIMP nuclear recoils. WIMP-nucleon spin-independent cross sections above 2.2×10^{-46} cm^2, for a WIMP mass of 50 GeV c^{-2}, were excluded at the 90% confidence level, in a world leading result. In September 2016, the decommissioning of LUX has started. It is planed to be completed by April 2017 [6,7].

In LUX, the LIP team is responsible for the detector control and the data processing systems. In addition, the group has the responsibility of the vertex reconstruction methods, and of several data analysis tools. In 2016, the LIP team coordinated the data processing effort for the entire run, a total of ~1 Petabyte of raw data, and was responsible for the maintenance and operation of the slow control system. An original method to describe the spatial distribution of the background events generated by the decays of ^{210}Pb and ^{210}Po on the PTFE walls was developed.

LZ – preparing the future

The LZ project proposes a 7-ton xenon detector based on the same time projection chamber (TPC) technology as LUX. It uses simultaneously liquid and gaseous xenon to obtain two different signals, so that dark matter can be distinguished from background noise. Its Concept Design was approved by DOE (DOE CD1 review). After having successfully passed the DOE CD-2/3b Review (April 2016) and the DOE CD3 Review, (Jan 2017), LZ has started the fabrication phase. Its underground deployment is scheduled for 2019 and commissioning is expected to start in Spring 2020.

In LZ, the LIP team keeps its main responsibilities: detector control system, data processing system, vertex reconstruction methods, data analysis tools. In addition, the group will handle background modeling and simulation, as well as the measurement, simulation and modeling of reflectivity and transmittance of detector materials. Last but not least, the team will be involved in the LZ physic program beyond dark matter searches, namely neutrino physics, neutrinoless beta decay and Xe rare decays. Key achievements in 2016 include the implementation of the control system for the System-Test at SLAC, the implementation and validation of a second generation drivers for communication with the sensors, and the Final Review of the LZ control system design. The reflectivity measurements of PTFE from three different manufacturers were carried out with the required accuracy and the results published. This was crucial to guide the choice of the PTFE for the LZ detector.

In 2017 the work will be focused mostly in LZ. LZ is the most competitive dark matter experiment in the world, with a high potential for detecting WIMPs or setting the ultimate limit before reaching the irreducible neutrino background.

Are neutrinos their own antiparticle?

After photons, neutrinos are the second most abundant particle in the Universe. The main goal of the SNO+ and NEXT experiments described below is the search for neutrino-less double-beta decay. The observation of this process would show that neutrinos are Majorana particles, i.e., that neutrinos are their own antiparticle.

SNO+ : neutrinos from the Sun and elsewhere

The Sudbury Neutrino Observatory (SNO) measured the oscillations of solar neutrinos, i.e., their transformations from one type to another. 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 Neutrino Physics 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. 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 [8].

Ready to go

The LIP SNO+ team is involved in detector calibration, data quality and data analysis. The planned 2016 activities were still affected by delays in filling the detector. Leaks were identified and fixed, but the detector was still not completely full by the end of the year, and so the activities that required data were affected.

A strong effort by the LIP Mechanical Workshop and Detector Lab was undertaken, in order to complete and test the Umbilical Retrieval Mechanism (URM) for the SNO+ calibration source insertion system. The production was finished in August, followed by the installation of electrical parts and mechanical and leak testing. URM #1 was shipped to SNOLAB in December. The second one will be built in 2017. Also, the installation at SNOLAB of the optical-fiber based system for PMT calibration was completed. We continued to prepare the water phase optical calibration analysis. The development of a fast calibration analysis validation algorithm with a limited data set was concluded. Concerning antineutrinos, the simulation study of a shielded neutron source with a collimator hole was finished, demonstrating the feasibility of calibrating the detector response to the direction asymmetry of antineutrino fluxes in the scintillator phases of SNO+. In addition, all the tools used to describe the reactor antineutrino signals in all phases were cross-checked and improved.

Commissioning data taking has just started. The water phase of SNO+ is a great opportunity to commission the hardware and software tools we have developed, to attempt some physics measurements, and further prepare the upcoming scintillator phases. The liquid scintillator phase is planned to start after a brief water phase with detector calibrations and physics data taking. We expect 2017 to be mostly dedicated to data taking, calibration and data analysis in the water phase, and to the preparation for the start of the next scintillator phases.

As for outreach, neutrinos were one of the special topics of the national Física 2016 conference, which took place in Braga, with several contributions from our group and an invited lecture by the Nobel Prize winner Arthur McDonald.

NEXT – golden neutrinos at the Pyrenees

NEXT (Neutrino Experiment with a Xenon TPC) is a neutrinoless double-beta decay experiment that operates at the Canfranc Underground Laboratory (LSC), in the Spanish Pyrenees. It is based on a novel detection concept for neutrinoless double-beta decay searches consisting in a TPC filled with high-pressure gaseous xenon and with capabilities for calorimetry and tracking. Key requirements are energy resolution and background suppression, given the large half-life of the searched decay. NEXT offers excellent performance in both aspects. Xenon has an isotope that decays to ββ (^{136}Xe), with a quite high natural abundance (9%) and easily enriched, with $Q_{\beta\beta}$ value acceptably high (~ 2458 keV), which makes it an obvious choice. Consecutive prototypes have shown excellent performance and robustness. The LSC Scientific Committee has recommended the installation of a first-phase of the NEXT detector, with a smaller dimension apparatus at the LSC, which will allow a clear demonstration of the unique NEXT topological signal. The NEW (NEXT-WHITE) apparatus is now in operation.

Choosing the perfect ingredient

The LIP team is dedicated to study the optimal gas mixture for use in the NEXT detector. A search for the ideal additive, which improves the necessary parameters without significantly compromising the scintillation yield, is being conducted. The first candidate was trimethylamine (TMA). Along the past year, the team continued the study of several aspects of the performance of Xe/TMA mixtures, namely charge multiplication and scintillation yields. The measurements were performed in several modular devices specially built and high pressure enabled, and Monte Carlo simulations were performed. TMA has been ruled out as it degraded the energy resolution and was not effective as wavelength shifter for the Xenon VUV scintillation. The absorption of Xenon scintillation by TMA, reportedly followed by re-emission, was a matter of disagreement in the scientific community, Our results, contradict the published results. The work was recognized by our partners and publications are being prepared.

In 2017, the group will study other Xe based mixtures of interest for the NEXT Collaboration. Our next study will be on CH_4, mainly on its effect on primary scintillation. The following study may be on CO_2, as it has some known advantages. These studies will be carried out in the systems custom built and, if needed, some new devices may have to be developed. Whenever necessary, Monte Carlo simulation studies will be carried out.

See references in page 36

// CONTACTS

Isabel Lopes (LUX/LZ), isabel@coimbra.lip.pt
José Maneira (SNO+), maneira@lip.pt
Filomena Santos (NEXT), filomena@coimbra.lip.pt

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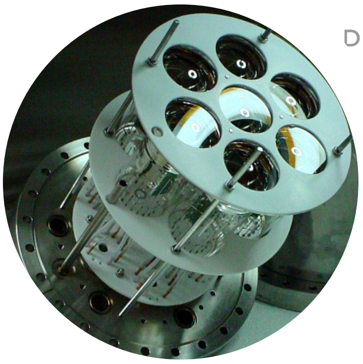
Development of new instruments and methods

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

Radiation detectors are sensitive to the passage of particles and able to measure some of its 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 and optical fiber calorimeters, as well as the development and operation of radiation detection systems for Health and Space applications.



DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

Detectors for particle and nuclear physics

Technologies to see the invisible

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.

RPC R&D

Due to their fast response, intrinsic radiation hardness and relative low cost per unit area, Resistive Plate Chambers (RPC) feature in many nuclear and particle physics experiments. This is a flexible technology, easily adaptable to many types of applications. It is also a speciality of LIP's detector development group.

The group presently works in a number of R&D lines that expanded the RPC applications range. One of these lines is the simultaneous high-resolution measurement of position and time (TOFtracker). A large area (~2 m^2) TOFtracker 3-layer cosmic-ray telescope was concluded and shipped to its commissioner CBPF, Brazil. It is a unique concept worldwide and a contribution on this subject was presented at the RPC2016 workshop and published [1]. A contract was signed with the company HIDRONAV, S.A. for supplying in 2017 a 4-layer TOFtracker telescope system for container inspection by muon tomography at sea ports (http:// macroescaner.com). Our comitment is to produce the telescope system and the construction has started. Also a scientific partnership was initiated with the TOMUVOL project (http://wwwobs.univ-bpclermont.fr/tomuvol/) for supplying a 2 layer TOFtracker to complement the project's detectors at a measuring campaign on the Stromboli volcano in 2017. Joint development was started on DAQ matters and construction was also started.

Another activity line concerns the development of low flux, autonomous and environmentally robust RPCs for deployment in remote locations, possibly with multihit capability in dense arrays. The operation of several chambers in the field at the Pierre Auger Observatory site in Argentina was continued and a report on this subject was presented at the RPC2016 workshop and published [2]. The bulk of the activity in 2016 was the preparation (detector design, production infrastructure, coordination with other partners) for the construction of 40 sensitive volumes for the MARTA engineering array in Auger. Two volumes were delivered to the Brazilian partner in São Paulo. An integrated gas control and environmental monitoring system was developed. We continued to support the operation of the TRAGALDABAS cosmic ray observatory. A Spanish group manifested interest in a MARTA-type telescope for cosmic-ray studies in Antarctica. Besides the development of RPC-based detectors, the team keeps an interest in the physical modeling of RPCs and in fundamental issues such as gas mixture properties and detector aging.

The LIP team has developed several other activities, such as high-rate studies within the AIDA2020 project (with the test of several candidate high-rate RPC electrode materials), developments for thermal neutron detection, and studies in view of the development of RPC-based Positron Emission Tomography (RPC-PET) for human use and for medical research. The TOFtracker developments are directly relevant for human RPC-PET and the new front-end electronics is relevant for animal RPC-PET. In several of these activities, the LIP RPC group cooperates with other LIP groups supporting their RPC-related activities.

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 commonly used. Nowadays, however, the ^{3}He crisis resulted 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. Boron-10, with a thermal neutron capture cross section close to the ^{3}He one, and with an occurrence in natural boron of ~20%, 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 10B4C, is only ~5%. To surpass this limitation one option is to cascade the converter layers.

A considerably high number of thin layers is needed to attain high detection efficiency. As a solution to face this challenge the LIP team proposed a new detector concept based on 10B4C coated RPCs, which takes advantage of the naturally layered configuration of RPCs. The feasibility of the proposed concept was successfully demonstrated in a monochromatic thermal neutron beam at ILL, Grenoble, which has shown e.g. sub-millimeter resolution capability. The work developed at LIP is now integrated into the Horizon-2020 EU research project Science & Innovation with Neutrons in Europe in 2020 (SINE2020).

In 2016, investigations of the surface resistivity of $^{10}B_4C$ coatings were continued, with special focus on tuning the sheet resistance for the $^{10}B_4C$-coated Multigap RPCs configuration. Two $^{10}B_4C$-coated RPCs with different gas-gap widths were designed and assembled in LIP. The $^{10}B_4C$ coatings were produced at the ESS Detector Coatings Workshop. In July 2016 the two prototypes were taken to TUM-FRM II in Garching (DE) for the experimental tests with neutrons. A detection efficiency of ~ 12 % was measured, which is as high as expected for a Single-gap RPC (~11% from MC simulations). From the evaluation tests it seems that thinner gas-gap's are more suitable for multilayer RPCs configurations when compared with wide gas-gap. The spatial resolution was measured to be FWHM ~ 236 microns for both x and y-directions (well below 1mm) which for a neutron gaseous detector is a remarkable result. A high spatial resolution combined with a timing capability easily in the nanosecond range opens the possibility of applying the $^{10}B_4C$-coated RPCs being developed by the LIP team e.g. for Timing-Resolved Neutron Imaging (to follow fast dynamics processes) or in Energy-Resolved Neutron Imaging at pulsed neutron spallation sources (neutron energy selected by a time-of-flight technique) such as the ESS.

The LIP team results were object of scientific highlights in the sites of the SINE2020 project, Phys.org and Neutrons source.org [3]. In September 2016, LIP organized at the University of Coimbra the SINE2020 General Assembly.

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 it 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.

High-pressure Xenon

High pressure Xe detectors can work at room temperature with good efficiency and adequate energy resolution, particularly for large areas, and have a much lower cost than competitors. The aim of the project is to develop and characterize a new type of high pressure gas proportional scintillation counter, conceived within the team: the MultiGrid High Pressure Gas Proportional Scintillation Counter (MGHP-GPSC). This detector has the advantage of featuring a photocathode deposit integrated in the gas volume, which avoids the need for optical windows and microstructures or photodiodes, also rendering it more ruggedized than the standard GPSCs. Additionally, it provides improved energy resolution, as the gain of this device is scintillation mediated, not involving any charge multiplication. The detector has been built and assembled during this year and is now under tests. The HP-Xe detector with the new geometry, previously designed, constructed at LIP's Coimbra workshop, is now being tested. The necessary custom-made electronics is also ready. The high pressure gas handling and purification system, adapted for this project from a previous version, is operational and the capability of recovering the Xe gas, a recent addition, has been successfully tested. With this new geometry we expect to achieve for 662 keV and a filling pressure of 5 atm, an increased efficiency (up to 25%), and a five times increase of both photocathode solid angle and detector active volume. As a result, we expect to at least double the detector gain, attaining an energy resolution closer to the intrinsic value.

From the expertise acquired and equipment developed, there is a serious possibility of expanding our work to the Astrophysics domain, where new gas mixtures for polarimetric studies are being sought, in this case for low pressure applications.

Ion mobility measurements

Measurement of the mobility of ions in gases is another activity line of the group. This is relevant in several areas, such as 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 several requests to study ion mobilities for specific gas mixtures. In 2016, a common project with GSI (Germany), VECC (India) and Uludag Univ. (Turkey) was approved in the scope of the RD51 Collaboration (CERN) and is currently underway. Mobility of ions in several mixtures were studied last year, namely, Ar-CO_2, Ne-CO_2, CO_2-N_2, Ne-CO_2-N_2, Xe-CO_2. The results obtained for Ne-CO_2, CO_2-N_2 and Xe-CO_2 mixtures have been published in peer reviewed journals and presented at several conferences [4,5].

Liquid Xenon detectors

Finding a Xe-based gaseous detection medium that will have low diffusion coefficients and high drift velocities, while maintaining a very good energy resolution is a challenge. During the past year, the LIP team studied the possibility of using wavelength shifting materials in contact with liquid Xenon, in particular tetraphenylbutadien (TPB). The study of stability of thin TPB films (wavelength shifter) in liquid xenon has been finalized and the results published [6]. A setup for testing new models of silicon photomultipliers in liquid xenon and liquid argon has been developed and is currently under assembly.

Still concerning liquid Xenon, and 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. The reflectivity measurements of PTFE from three different manufacturers were carried out with the required accuracy.

Scintillating Detectors and Optical Fibres

LIP has expertise in detectors based on radiation hard scintillators and scintillating or wavelength-shifting (WLS) optical fibres and decisively contributed to the ATLAS Tilecal calorimeter and to a number of other projects. The group is now involved in R&D for the TILECAL upgrade, in which a set of special scintillators located in the calorimeter gap and crack areas, and the respective WLS fibres, will be replaced.

In 2016, work on the study of alternative scintillator-WLS fibers couplings to improve light collection in the Tilecal gap/crack scintillators started at the LOMAC facility. In addition, a new setup to cut/polish the bundles of fibers was prepared and the essential maintenance of the aluminization setup was performed. Aluminization will start early in 2017.

NUC-RIA – experimental nuclear astrophysics

LIP's Experimental Nuclear Astrophysics group participates in the R3B (Reactions with Relativistic Radioactive Beams) collaboration of the future FAIR (Facility for Antiprotons and Ion Research) facility at GSI, Darmstadt (Germany) [7,8].

The team has responsibilities in the execution of several experiments within the collaboration and performs data analysis of neutron knock-out reactions in halo nuclei at the present setup of the collaboration, and participates in the development of a new electromagnetic calorimeter (CALIFA, the R3B CALorimeter for In-Flight emitted pArticles detection). The activity at R3B and FAIR is complemented in the past years with additional participation in nuclear reaction experiments at other radioactive ion beam facilities across Europe, namely ISOLDE at CERN, in topics related to nuclear structure and nuclear astrophysics. The group has the capability to operate both on large scale facilities, as a part of large collaborations, as well as to take full responsibility on small scale experiments covering all aspects needed for their preparation, execution and analysis.

During 2016, the group was responsible for an experiment producing mono-energetic, high-energy ($E\gamma > 10$ MeV) photons to benchmark the response of the future R3B calorimeter CALIFA. A total of 128 individual CsI(Tl) crystals with their corresponding readout electronics were mounted for the measurement of the high-energy photon decay from the reaction ^{27}Al(p,g)^{28}Si at the Tandem laboratory of the LATR/CTN facility in Lisbon. The experiment was performed during November 2016, in strong collaboration with groups from the University of Santiago de Compostela (Spain) and Technical University of Munich (Germany). The data successfully recorded will be extremely valuable to benchmark and improve the existing photon reconstruction algorithms for upcoming experiments at FAIR. The analysis of the neutron breakup reaction data measured at the GSI facility on the halo nuclei ^{15}C and ^{11}Be was concluded and the results were presented at the R3B collaboration meeting in September 2016. At ISOLDE, the group participated in a beta-decay experiment on neutron rich nuclei in 2016. For 2017, the LIP group is officially involved in the planned experimental runs.

The LIP group further develops technology transfer activities, namely contributions to the study of electron beam food irradiation in the framework of the International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP) devoted to the study of the effects of radiation on fresh fruits. The group is in charge of the simulation and modeling of the radiation transport. The participation in this CRP was extended by the IAEA until 2019. The group is a member of the approved COST action ChETEC (Chemical Elements as Tracers of the Evolution of the Cosmos).

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// CONTACTS

Paulo Fonte, fonte@coimbra.lip.pt
Rui Marques, rui@coimbra.lip.pt
Daniel Galaviz, galaviz@lip.pt

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 a natural application area in the fields of medical imaging, radiotherapy instrumentation and dosimetry. In fact, particles have been used in medicine ever since the discovery of X-rays. Today, particle accelerators and detectors are used in clinical treatments and to look inside the human body. These applications require truly multidisciplinary collaborations, combining the skills of physicists, doctors, radiologists, engineers and programmers. Ongoing projects include the development of RPC-based PET scanners, adaptive algorithms for gamma-camera image reconstruction, a method to produce an image of a tumor's morphology in real time for patients undergoing radiotherapy, a new system for dosimetry in mammography tests, and a spinoff company dedicated to the development of a PET scanner based in scintillating crystals.

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 travelling 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. Already two avenues of development were identified: high-sensitivity, whole body human PET, and high-resolution animal PET.

The first RPC-PET scanner for mice is installed at ICNAS (an institute of the University of Coimbra dedicated to Nuclear Medicine) since August 2014. Continuous support was provided to the routine bio-research activities at ICNAS using our prototype animal PET. In 2016 more than 150 PET examinations were performed. The detectors operated flawlessly, but some need for improvement on the auxiliary instrumentation was identified. We believe the small animal RPC-PET approach has been sufficiently tested and it is ready for pre-commercial deployment. We initiated and made good progress on the construction of a second, pre-commercial, animal PET, incorporating several developments such as a new front-end and trigger electronics and data acquisition system, an integrated gas control and environmental monitorization system and a friendly operator and data-user interface software, with multi-user capability and browser-server architecture.

On the human PET front, the basic structure of the scanner was long ago designed and simulated. The readout system envisaged for the human scanner was successfully tested during 2016 in the TOF-Tracker setup MASTER built, for different purposes by the LIP RPC group. The LIP group, in conjunction with its partners, has the necessary competences to perform all steps of the RPC-PET scanners development, including evaluation.

Gamma cameras: from dark matter to the hospital

Adaptative algorithms developed at LIP for position-sensitive neutron and dark matter detectors can used in medical imaging devices — for example to improve the calibration of gamma cameras in cardiology tests. In the past years, we confirmed, with simulation and experimentally, the applicability of our auto-calibration and position reconstruction techniques to both clinical gamma cameras of classical design and a compact high-resolution camera with silicon photomultiplier (SiPM) readout. The prototype of a compact gamma camera with SiPM readout was built. Two versions of the front-end electronics were developed. Work on the optimization of the compact gamma camera geometry was performed by means of Monte Carlo simulation and confirmed experimentally. Sub-millimeter spatial resolution was obtained [1,2]. We also created an integrated software tool that incorporates the whole development workflow. The research on the use of machine learning algorithms for position and response reconstruction has been focused on two methods: artificial neural networks (ANN) and k-nearest neighbour (k-NN). Both methods were incorporated into the LIP ANTS2 software package. In 2016, the main objective of the work on ANTS2 was to extend the range of its possible applications in the area of scintillation detection. In particular, the detector geometry module was significantly upgraded to increase flexibility. More realistic models for several elements of detector design were implemented in order to process data from multi-head detector systems, such as PET. The simulation module of the ANTS2 package was validated with the compact camera prototype. We collaborate with medical imaging units of Coimbra University (ICNAS and AIBILI), Coimbra University Hospital and the Radiation Detectors and Applications Group at Politecnico di Milano.

Orthogonal ray imaging

A LIP project developed in partnership with two Portuguese Oncology Institutes, the Hospital of the University of Coimbra and several medical research centers aims to improve traditional 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-rays emitted orthogonally to the treatment beam and detected by a multi-slice scintillating detector, which is currently in construction. The rotation-free and low-dose imaging capability of OrthoCT are two of its more promising strengths. The project is moving forward in several fronts at LIP Coimbra, in both simulation and experimental work [3,4].

Realistic GEANT4 simulations show that OrthoCT will be useful in assisting lung treatments. Similar simulation results indicate usefulness in head-and-neck irradiation where the beam crosses theoretically empty sinuses, although not for prostate cancer. Visualizing very-small, implanted gold fiducial markers is possible with a very large reduction of the dose imparted onto adjacent organs like the bladder or the intestine. The team will move to non-trivial realistic treatments in order to increase evidence of the usefulness of OrthoCT for both on-board imaging and real time treatment monitoring.

Experimental work is also ongoing, with a single-line, very-long detector having proven its feasibility to read gamma rays. An OrthoCT experiment will soon be carried out at a therapeutic linac. In collaboration with LIP's mechanical workshop and Detector lab, we are putting forward a small-scale OrthoCT system expected to be ready within the next couple of months so that data taking at a therapeutic linac can occur within the next half year.

Dosimetry

LIP has a long standing expertise in dosimetry. R&D lines of work are combined with the provision of services to society in areas related to environmental radiation and public health.

Researchers at LIP have develop a plastic scintillator dosimeter that could be an asset to quantify the dose in radiotherapy treatments. Plastic scintillation dosimeters provide a low cost alternative to dose monitoring, and can be manufactured with several shapes and sizes. The work carried out with kV-CBCT beams at the Radiotherapy Service of Hospital de Santa Maria in Lisbon has shown that this type of dosimeter can be competitive with other systems for beam qualities between 100 and 120 kV.

An environmental radon survey conducted by LIP's dosimetry group to assess the radon concentration in public drinking water sources around Covilhã. In this study 23 of 33 samples had radon concentration levels above 100 Bq/L, indicating that should be declared not safe for drinking. A radon progeny detector based on a windowless photodiode was developed, weach can give real-time information on radon gas concentration. A detector prototype based on a windowless PIN-photodiode was built and tested. During 2016 the intervention in the community continued with radon air and water analyses made for two companies in Sortelha and Covilhã.

STCD – Spin-off technology for cancer diagnosis

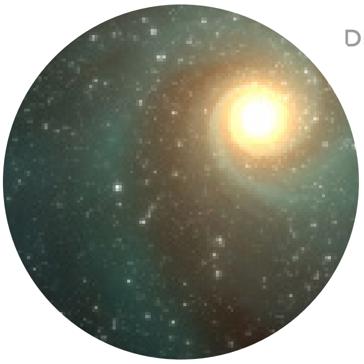
The STCD group was created in 2004 around the development of a new Positron Emission Tomography scanner (ClearPEM) for breast cancer diagnosis, exploiting technologies developed at LIP for the CMS experiment at the LHC. The ClearPEM project was developed by a national consortium of research institutes and clinical centers under LIP's leadership. The consortium collaborated with institutes of the international Crystal Clear Collaboration, namely CERN Switzerland, INFNMilano Italy, Univ. Hospital Nord Marseille France, Hospital San Gerardo Monza Italy.

The activities of the group are carried out at the lab infrastructure TagusLIP done in coordination with the start-up PETsys. The research lines pursued by the group are the following: development of new gamma ray detectors with improved performance for PET Time-of-Flight; development of new front-end and data acquisition systems, including electronics, firmware and software; construction and exploitation of demonstration PET scanners based on the above technologies, and associated calibration and image reconstruction software; development of detectors for other medical imaging applications. The group continues to give technical support to the operation of two ClearPEM scanners (installed at ICNAS Coimbra and Hospital S. Gerardo Monza), and two EndoTOFPET detectors (installed in Cerimed Marseille and TUM Munich).

In 2016, the new TOFPET2 ASIC was tested between March and July. The expected performance was confirmed. A chip layout problem was identified that motivated a new MPW submission in September. The chips were received in January 2017 and are under test. A new frontend system based on TOFPET2 aiming at improved time resolution, energy resolution and rate performance was developed. In collaboration with PETsys, firmware implementing extended triggering capabilities of the present SiPM readout system was developed. The obtained results were presented at several international conferences, including TWEPP 2016 and IEEE/NSS/MIC 2016 [5,6].

// CONTACTS

Vladimir Solovov, solovov@coimbra.lip.pt
João Varela, joao.varela@cern.ch



DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

Space applications

Into outer space

Space exploration in one of the key areas of application of particle physics instruments and methods, and this has been strategic for LIP. Over the last decade, LIP became a recognized partner in the Space community, and particularly in the Portuguese participation in European Space Agency (ESA). This line of activity has two groups, one based in Lisbon and another based in Coimbra. Both groups have strong competences in the development of tools and studies based on the GEANT4 simulation toolkit for space applications, data analysis and instrumentation for Space missions.

Space Rad: Radiation environments and more

The Space Radiation Environment and Effects group at LIP-Lisboa has now more than 10 years of expertise in the development of applications dedicated to the study and measurement of the radiation environment in Space and of its effects. The group has been developing its activities mostly in the framework of contracts with ESA. These activities have been a source of collaboration between LIP and other institutes, companies and the industry. LIP is recognized by ESA as a Portuguese reference for Space Radiation and Environment Studies [7,8].

The RADiation hard Electron Monitor (RADEM) for the JUICE ESA mission to the Jovian system, with launch foreseen in 2022, is developed by a consortium of institutes and industry: LIP and the Paul Scherrer Institute in Switzerland, EFACEC SA and IDEAS from Norway. In 2016, the radiation analysis was performed, centred mostly on finding the minimum mass needed in order to shield the components and sensors from the harsh Jovian radiation environment. LIP leads the work in the ECo-60 contract for validating tests of several types of electronic components for the JUICE mission, where they will be exposed to the hard Jovian electron radiation environment. During 2016 four irradiation campaigns were conducted at CTN and Hospital de Santa Maria. The CODES contract was closed in the beginning of 2016 with the release of the CODES web based engineering framework, using GEANT4 to predict Single Event Effects in electronic devices. LIP has been collaborating with EFACEC SA and EVOLEO SA in several contracts regarding AlphaSAT, the largest ESA telecom satellite, in geostationary orbit since July 2013. The exploitation of dMEREM, the detailed Martian Energetic Radiation Environment Model, based in GEANT4, which was developed by LIP for ESA, continues. The ongoing work consists on the upgrade of dMEREM, its validation with data from Mars Curiosity Rover radiation detector (RAD), and on its use in assessing radiation hazards in future manned missions to Mars and also for astrobiology studies.

i-Astro: astrophysics instrumentation in Space

The Space Instrumentation for Astrophysics Group at LIP-Coimbra has strong competences in the development of detector concepts for polarized x-rays and gamma-rays, both in simulation and hardware testing. The group is a partner of three major international projects in high-energy astrophysics: H2020 AHEAD (Activities in the High Energy Astrophysics Domain), e-ASTROGAM mission candidate (enhanced-ASTROGAM, ESA M5 call) and the ESA pre-selected XIPE (X-ray Imaging Polarimetry Explorer) mission. Polarimetry in high-energy astrophysics is little explored and has great potential to open a new scientific observational window. In 2016, the group remained focused on the development of focal plane instruments based in CdTe and in gas filled detectors, with polarimetric capabilities. The priority science objectives of AHEAD work package 9, "Assessment of gamma-ray experiments", as well as the instrument configurations to be simulated, were chosen. e-ASTROGAM mass model simulation was assigned to our group. In addition, we kept contributing to the development of the main instrument of the XIPE mission [9,10].

In June 2017, ESA will decide if XIPE will be launched in 2026, among the 3 pre-selected missions. Our group has the task of optimizing the gas pixel detector (GPD) gas mixture. This will allow for a better reconstruction of photoelectron emission direction, and therefore a better determination of the degree and angle of polarization. The first simulation results on electron production and transport for Xe- and Ne-gas filled GPD were obtained. This task will be developed in a larger scale effort involving the Gaseous and Xenon detectors R&D group, in particular for charged particle mobility studies. A spin-off project BioMeXRay (Biometals Detection by X-Ray Fluorescence) provides an opportunity to apply the same methods and techniques of Space instrumentation development to biomedical sciences and contribute to the impact of our scientific work in society. The optimization of the X-ray fluorescence spectrometer parameters are almost concluded and the development of measurement/analysis methods by X-ray fluorescence in brain and eyes tissues is under way.

// CONTACTS

Patricia Gonçalves (Space Rad), patricia@lip.pt
Rui Silva (i-Astro), rcsilva@coimbra.lip.pt

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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 has been participating in several projects for the development, deployment and operation of the computing infrastructure for the LHC experiments, and also for generic use. These activities are mainly focused on grid computing and cloud computing technologies.

Grid computing has the goal of integrating, in a transparent way, resources which may belong to independent organizations, hiding their specific features and presenting an homogeneous interface to users. In this way, large computing infrastructures can be created from spread resources, appearing to users as a unique system. LIP is working on combining Grid computing with Cloud computing, to enable federated access to distributed virtualized computing resources. Cloud computing is gaining momentum in industry and science as a flexible way to access computing and storage capacity.

LIP participates in some of the largest R&D projects in this field. LIP 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 this context, LIP in partnership with FCCN and LNEC is leading the National Distributed computing Infrastructure (INCD), an e-infrastructure that is part of the Portuguese Science Foundation Roadmap of Research Infrastructures of strategic relevance.

COMPUTING

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 example of this. The LHC distributed data simulation, processing and analysis lead 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.

Distributed computing and digital infrastructures

The LIP distributed computing and digital infrastructures group provides information technology (IT) services to LIP and to its research groups.

The group's main line of work is the research, development and provisioning of services and infrastructures for scientific computing. The group is especially focused on distributed computing technologies including grid, cloud, high throughput (HTC) and high performance computing (HPC).

The group operates most LIP core IT services, including computing and data services for simulation and data analysis that support the LIP research, such as the participation in the LHC. The development of the IT services and competences is backed by participation in R&D projects and e-infrastructures at national and international level. At national level, activities are now focused on ramping-up the National Distributed Computing Infrastructure (INCD), in the context of the FCT infrastructures roadmap, and on operating the LIP Tier-2 facility, part of the Worldwide LHC Computing Grid (WLCG). At international level, activities are shaped by the participation in European projects which currently include the H2020 projects EGI-ENGAGE and INDIGO-DATACLOUD, and by the participation in international e-infrastructures such as the European Grid Infrastructure (EGI) and Iberian Grid Infrastructure (IBERGRID) [1,2].

In 2016 the Tier-2 executed 1,809,210 jobs amounting to 65,485,165 normalized processing hours to ATLAS and CMS. This is an increase of ~ 21% in comparison to 2015. The gain was obtained with multicore jobs and cloud technologies. LIP has been one of the WLCG centres pioneering higher efficiency with multicore jobs. The group organized the 2016 WLCG Collaboration Workshop in Lisbon, followed by a data preservation DPHEP Workshop, each counting more than 130 participants. The group continued to coordinate IBERGRID operations, enabling the sharing of computing and data resources at pan- European level for the benefit of research experiments and projects. LIP contributed to the LifeWatch competence centre in EGI and together with CIBIO established the Portuguese GBIF portal delivering access to Portuguese biodiversity data. The service is hosted at the INCD cloud. In the INDIGO-DataCloud project, the group successfully coordinated the "Pilot Services and Release Management" supervising the software quality assurance, release management, pilot services and exploitation activities of this large software R&D project. During the project review in November this work was praised for its innovation and excellence. EGI, INDIGO and EUDAT were pushed by the EC as the base building blocks for the European Open Science Cloud (EOSC) [3].

The group also operates many core IT services for LIP. In 2016, the LIP Lisbon computing farm has been moved and merged with the NCG computing farm. This consolidation enabled lower operational costs and higher efficiency, and was a mandatory step to enable the migration of LIP Lisbon to new premises. The commercial and academic network bandwidth for the NCG services has been improved. Having the core computing and storage equipment at NCG will enable further service improvements. The adoption of cloud computing and containers technology to support the LIP services and applications will be pursued, aiming at improving the flexibility, resilience and management. At the FCCN workshop 2016, the INCD cloud was announced as a beta service open to the community. INCD, through LIP, continued to support national researchers and projects. Adherence has increased with new users, organizations and projects especially from the biomedical domain, exploiting the HPC, HTC and cloud resources. The INCD pilot GPGPU service and the large memory systems have been heavily used for genome research. A project proposal for the development and enlargement of the INCD infrastructure was submitted in July under the umbrella of the FCT roadmap of research infrastructures. The project partners are FCCN, LIP and LNEC. The proposal has been approved in early 2017.

Advanced Computing

The Minho advanced computing group joined LIP in 2014. Without abandoning research in Computer Science and Engineering, the team has been directing its activity to areas more related to the general interests of LIP. In particular, it has been supporting the development and optimization of code applications related to particle physics, with some emphasis on the optimization of distribution strategies for access to large volumes of data, in order to improve efficiency and execution time. Another focus of our activity has been on advanced training in Scientific Computing. The group is also responsible for the administration of a local High Performance Computing (HPC) cluster that supports the running of the data analysis applications developed by other groups in LIP.

In 2016, the group cared for the upgrade and maintenance of the local cluster infrastructure. The group collaborates with other LIP groups in computing projects, particularly with the ATLAS group. A programme of training activities for young researches started with the course "The Basics of the LINUX Command Line" and will be pursued in 2017 with further training offers.

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// CONTACTS

Jorge Gomes (Distributed Computing), jorge@lip.pt
António Pina (Advanced Computing), pina@di.uminho.pt

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 not only to the CERN projects but also to research groups inside and outside LIP and to external companies. The work developed by the MW is complemented by the Detectors Lab, as many of the projects developed by LIP need the competences of both facilities. Over three decades, the two infrastructures assured excellent quality support to gaseous detector R&D both at LIP and National level, as well as to the participation and responsibilities of LIP in large collaborations, namely CP-LEAR, DELPHI, HERA-B, ATLAS, HADES, Auger, LUX and SNO+.

During 2016, the project requiring more resources (around 60%) was the final construction, assembling and test of the Umbilical Retrieval Mechanism (URM, mechanics for the PMT calibration system) for the SNO+ experiment. The apparatus was shipped to SNOLAB is December. Other activities included the construction of a cryostat for the Chemistry Department of the University of Coimbra; mechanical pieces for LIP-LUX/LZ activities and for a test setup of the Orthogonal ray imaging project; aluminium boxes and auxiliary mechanical pieces for muon tomography RPC telescopes for the Hydronav company (MUTT project) and for a volcano tomography project (TomuVol); a wheel system to transport and hold the HADES-RPC sectors; mechanics for a prototype cloud chamber; an aluminium tight gas box to host a Multi-Gap RPCs with $^{10}B_4C$ coatings for position sensitive thermal neutron detectors; preparation of scintillators for the Radiation, Health and Environment group; final works related to high pressure chambers for detector testing in the framework of the RAD4Life project; mechanical pieces for elements of the 30th anniversary of LIP exhibition and some other small works for the Coimbra Physics department.

// CONTACTS

Alberto Blanco (Workshops), alberto@coimbra.lip.pt
Luís Lopes (Detectors Lab), luisalberto@coimbra.lip.pt

Detectors laboratory

The detectors laboratory (DL) was created at LIP's foundation with the main 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.

During 2016, the main activities were related to the R&D and production of three different types of large area RPC-based systems used in projects and collaborations in which LIP is involved: MASTER-Rio, MARTA-Rio, MARTA-FCT/FAPESP, MUTT, Tomuvol. Our contribution covers all required tasks, from project design to detector installation and maintenance, including the development of tools and/or instruments to control/monitor the detector performance. We adapted the detector to the individual requirements of each application, following a procedure similar to the one used in industry. During 2016, more than 40 m^2 of RPCs were built, including timing and trigger (counting) detectors. We develop from scratch the detector sensitive volume, the gas control and monitoring system and the monitoring of all the environmental properties that could affect the detector performance.

Another important activity, which consumes about 35% of the human resources of the DL, is to assist the groups in their R&D activities. The DL contributes with technical work and added value in the following projects: RPC-PET, SNO+, MASTER-Rio, CriostatoLaserlab-DQUC, LZ (system upgrade), HADES, AIDA2020, SINE2020, GSPC. LIP, OrthoCT.LIP and muTT/Tomuvol. Layout, loading and testing PCBs of home made electronic boards. Concerning education and outreach, the DL supports the construction of the LIP spark chambers (purchased by different institutions worlwide) and, currently, of a prototype cloud chamber.

TagusLIP laboratory

The TagusLIP Laboratory is a LIP research infrastructure installed in 2004 at the Lisbon Science and Technology Park (Taguspark). The campus is home to a University (IST), several research centres, as well as a large spectrum of startups and PMEs. TagusLIP was conceived as a generic infrastructure for the development of radiation detectors 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 (Cadence), for firmware development (Xilinx and Altera), and for the design of printed circuit boards (Altium). The TagusLIP has a computing and data storage infrastructure, suitable to software projects in various areas, such as data acquisition, equipment control, data analysis and image processing. The TagusLIP is licensed for the use of radiation sources needed to develop and test new instruments in nuclear medicine.

The PETsys start-up company has recently been using the TagusLIP infrastructure for the development and validation of Time-of-Flight PET technology. The company has assembled a TOF-PET demonstrator ring and performed the validation of the system using radiation sources.

In 2016 the main activities at the TagusLIP Laboratory where the development and test of a new ASIC for Time-of-Flight applications (TOFPET2); with the startup PETsys, the development of readout and data acquisition systems for PET-TOF scanners; and the development and test of a new frontend ASIC (TOFFEE) for the readout of Ultra Fast Silicon Detectors (UFSD) developed for time measurements in the proton spectrometer CTPPS of the CMS experiment. The TagusLIP Laboratory is a member of the ERAMMIT European consortium that submitted the proposal “Enabling Research Access for Multi-parametric Molecular Imaging Technologies” to the EU Infrastructures call INFRAIA-02-2017. The aim of the ERAMMIT Starting Community is to enhance the access to Europe’s best research infrastructures to solve key technical challenges restricting the wider adoption of MMIT for personalised medicine. In this context the TagusLIP Laboratory will provide access to the necessary instrumentation for R&D on radiation detectors and associated electronics and data acquisition.

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 2016 the e-CRLab had two main activities: the development of MARTA instrumentation and the testing of radiation damage of components for ESA. Within the Auger MARTA project to operate RPCs outdoors in the Argentine Pampa, the e-CRLab is responsible for the development and operation of the prototype electronics (PREC). The system was characterized and the results published. The PREC has also been adopted in other RPC detectors. The engineering prototype of the MARTA front-end electronics based in the MAROC ASIC was designed, built and is now under testing.

In the context of the ECO-60 project of the LIP SpaceRad group, the e-CRLab was responsible for the development of the testing procedure and test system for Co-60 irradiation in different conditions of several components, in the context of the preparation of the ESA mission to Jupiter. In 2016 several irradiation campaigns were performed with Co-60 sources at IST-CTN and ESA-ESTEC, and with electron beams at Hospital Santa Maria and at RADEF, Finland. The components were tested during the irradiation campaign and were afterwards brought to LIP to be tested during the annealing phase.

// CONTACTS

João Varela (TagusLIP), joao.varela@cern.ch
Agostinho Gomes (LOMaC), agomes@lip.pt
Pedro Assis (e-CRLab), pedjor@lip.pt

LOMaC
(Laboratory of Optics and Scintillating Materials)

The laboratory was established in the framework of the ATLAS experiment, to provide support for detector R&D and construction. It focuses on the characterization of plastic scintillators and clear, scintillating and wavelength shifting (WLS) optical fibres. The laboratory was set up in collaboration with CFNCUL (Centro de Física Nuclear da Universidade de Lisboa), where it was located. The laboratory was used to select radiation hard scintillators and WLS fibres for the ATLAS Tilecal calorimeter, and for the massive preparation and quality control of the WLS fibre sets used in the calorimeter. It was also used for several detector R&D projects: DELPHI, ALFA, RD52/DREAM, and SNO+. The laboratory is equipped for testing and preparation of scintillators, optical fibres, photomultipliers and related electronics. The main test setup is used for the characterization of plastic WLS or scintillating optical fibres in large numbers, using holders for the scan of up to 32 fibres at a time. It can use both direct radiation from a ^{90}Sr radioactive source to produce light in the fibres or use an additional scintillator as light source. There are additional setups to test scintillators and PMTs. There are facilities for the preparation and aluminization of plastic optical fibres by magnetron sputtering, and the facility allows the deposition of aluminium mirrors in the top of fibres with variable length up to 3 m.

In 2016, work on the study of alternative scintillator-WLS fibers couplings to improve light collection in the Tilecal gap/crack scintillators started at the LOMAC facility. In addition, a new setup to cut/polish the bundles of fibers was prepared and the essential maintenance of the aluminization setup was performed. Aluminization will start early in 2017.

Competence Centers

LIP has a set of skills, technologies and tools that are shared by different groups, often in complementary way. These competences, which are at the basis of our research projects, can also provide services and open collaboration possibilities to a wider community. For this reason, an organization in competence centers is being pushed forward. 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. The first competence center has now been set up and will become effective in 2017.

COMPETENCE CENTERS

Simulation and Big Data

Simulation and Big Data competence center

In the past years a wealth of know-how in data analysis software and simulation tools has been accumulated among the various LIP groups. These include physics models and Monte Carlo generators, detector simulation tools and big-data handling techniques. Implementing a competence centre in this area aims primarily at fostering an effective collaboration/coordination among the various groups that can boost the capability to exploit the existing expertise, both internally and, externally, towards the university and industry. At present two of the areas of competence have already emerged as having the span and the potential to fulfill this purpose.

GEANT4

The GEANT4 simulation toolkit has long been used at LIP in a variety of fields, from biomedical applications to detector performance studies or space radiation effects. LIP has been a member of the GEANT4 collaboration for more than ten years. Important expertise has been accumulated both from the user point of view and at developer level, with a particular in depth knowledge of some of the physics processes of the GEANT4 kernel. Notably, GEANT4 based applications were developed at LIP in the context of international collaborations, with recognized impact in the understanding of detector performance. Also, LIP members are responsible for teaching advanced detector simulation techniques.

For 2017, the main concern will be the coordination among LIP GEANT4 experts, to foster the capability of LIP to offer courses both in the curricula of the universities and in advanced training schools and workshops. Steps should also be undertaken in identifying the potential of our competences for industry. LIP's participation in the GEANT4 collaboration will continue, and possible new areas of intervention will be identified.

Big Data

LIP has been involved in the analysis of the extremely large amounts of data produced by the experimental collaborations in high energy physics. Many LIP members have actively contributed to the implementation and development of elaborate multivariate techniques aiming at a vast range of applications: from the reconstruction and identification of physics objects in the detectors, to the search for rare events. Methods such as likelihood analyses, neural networks and boosted decision trees, for instance, were successfully used by different LIP groups in the context of their scientific activities. In a complementary way, the efficient processing of the available data has also been a concern and LIP has developed some expertise in the optimization of the available resources. It should be noted that the analysis of the typical amount of data produced by the experiments integrated by LIP is extremely demanding on the underlying computing, storage and networking infrastructures. As is typical of big-data applications, large volumes of data must be written, stored read and processed over time, with the added difficulty that data must often be revisited and re-analyzed, both at the GRID and locally. The complexity and hardware requirements of analyses using machine-learning techniques is even bigger and, therefore, using the computing resources efficiently is an imperative.

Some of the methods used and developed by LIP in the context of big-data and machine learning are currently being used in an industrial context, aiming at significantly improving the quality control in production lines.

During 2017 it is planned to increase the collaboration between the different groups in this context, aiming at exploring synergies and fostering the expertise in the efficient analysis of Big Data, exploring recent advances in the field, such as anomaly detection, cross-validation, multi-dimensional re-weighting and imaging, and deep learning. The application of such techniques and competences to contexts beyond High Energy Physics will also be pursued.

// CONTACTS

Bernardo Tomé, bernardo@lip.pt
Nuno Castro, nuno.castro@cern.ch

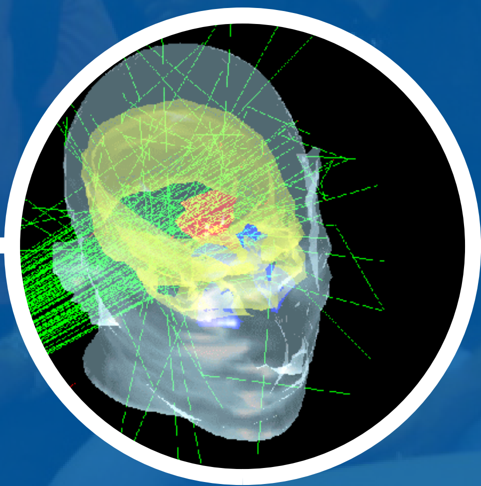
Communication, Outreach and Education

Advanced training

// SCIENCE AND SOCIETY

Technology transfer, industry, spin-offs and societal impact

Radiation, health and environment



Communication, outreach and education

Support to education in science and technology and public engagement with science are central for LIP. LIP aims to inspire the young generations to pursue careers in science and technology and offers engagement and training opportunities to teachers and students.

The LIP-ECO office, Education, Communication, Outreach and Advanced training

The LIP Education, Communication, Outreach and Training (ECO) office aims at fostering and coordinating the ECO related activities carried out at LIP. It has three main (interrelated) pillars: corporate communications; education and outreach and advanced training. Its priorities for 2016-2017 include setting up a more efficient strategy for communicating LIP's image, activity and impact; to consolidate the existing outreach and education activity program, in partnership with Ciência Viva, CERN and IPPOG; and to increase LIP's capability to attract the best graduate students and provide them with adequate integration and excellent training. The following audiences have been selected as immediate priorities: the LIP community and our direct partners (associates, funders, academics); the school community, and university students in Physics and Engineering. LIP-ECO involves all three LIP nodes, which are represented in its core teams.

The LIP-ECO office coordinates the preparation of LIP's annual report and the (quarterly) LIP-news bulletin, manages LIP social media and web site news, issues press releases as appropriate, interacts with our partner communication offices and gives support the preparation and advertising of public events organized by LIP. A full renewal of the LIP public web site is ongoing.

2016 highlights

Arthur MacDonald, Nobel for Physics 2015, in Portugal in September, invited by LIP and the Public lecture at the Pavilion of Knowledge in Lisbon, visited the LIP mechanical workshop in Coimbra, where instrumentation for the calibration system of SNO+ is being constructed, and open the annual meeting of the Portuguese Physic's Society in Braga.

The exhibition "Partículas, do bosão de Higgs à matéria escura" (Particles: from the Higgs boson to dark matter) was the key element of the celebration of LIP's 30th anniversary. From February to May 2016, the exhibition has been shown in the three cities where LIP is present, at the Universities associated to LIP. It gave LIP remarkable institutional visibility and had more than five thousand visitors. On the 9th of May, LIP's anniversary was celebrated in a public session with an invited talk by Rolf Heuer and the presence of the Minister of Science,Technology and Higher Education. The exhibition is focused on the big challenges of particle physics for the next decades. After an introduction about LIP, particles and detectors, the visitor was "accelerated" to the different modules: quarks and gluons, the Higgs boson, antimatter, neutrinos and dark matter. In each module, what we know and what we don't yet know was highlighted together with LIP's contributions and relations to technology and innovation. The exhibition was produced by LIP in partnership with a professional company and had the support of Agência Ciência Viva. CERN Media Lab's LHC interactive tunnel was shown.

From September 30th 2016 (European researcher's night) to May 3rd 2017, the exhibition could be visited at Planetário Calouste Gulbenkian in Lisboa. In the three cities, public talks were regularly given by LIP's scientists on topics related to the exhibition. An oral communication on the exhibition was presented at the national science communication conference SciCom.pt [1].

LIP flagship initiatives for the school community

IPPOG's International Masterclasses in Particle Physics
Under the coordination of LIP, more than 1500 participants gathered in 15 sessions all over the country: Aveiro, Beja, Braga, Bragança, Coimbra, Covilhã, Évora, Faro, Funchal (Madeira), Lisboa (2 places, 3 sessions), Ponta Delgada (Azores), Porto, Vila Real, and with our remote support in São Tomé and Príncipe.

CERN Portuguese Language Teachers Programme
Under the responsibility of LIP and with strong support from CERN and Ciência Viva, the school was held in the beginning of September and attended by 22 Portuguese teachers, 20 teachers from Brazil, 1 from Mozambique and 1 from São Tomé and Príncipe.

Ciência Viva's "Science in the Summer" programme
LIP proposed several internships in Lisboa and Coimbra and hosted 20 students for 10 days to learn about experimental particle physics and directly experience the work of scientists in the field.

Talks at schools and public lectures
More than 50 outreach talks were given by LIP scientists at schools and in other settings, on particle physics, space and related technologies.

References:

[1] "The role of networks in the local communication of big science organizations: the example of Portugal at CERN". SciCom.pt, Lisboa, 2016

// CONTACTS

Pedro Abreu (Outreach), abreu@lip.pt
Catarina Espírito Santo (Communication), catarina@lip.pt

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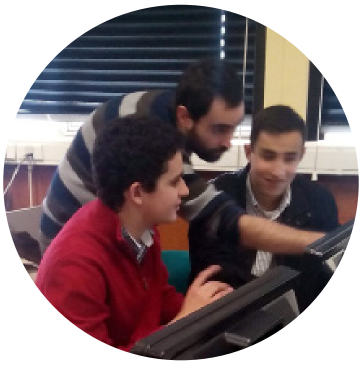
The LIP interactive panel
An interactive touch panel is currently under development at LIP-Minho. It can be used to introduce LIP, particle physics, or a variety of subjects. The flexible structure can accommodate a variety of contents and media supports, namely 3D representations of detectors and other structures. The emphasis of this communicational approach is put on the interactivity of the presented contents. The panels will be permanently on display at the Braga and Lisbon LIP premises and can also be used in different events and locations.



Advanced training

At LIP, we train the scientists of tomorrow. PhD and master students at LIP go through a truly international training, in the framework of international collaborations. LIP hosts undergraduate students in schools, workshops and summer internships.

The laboratory permanently hosts tens of PhD, Master and Bachelor students, who actively work within LIP's research groups. LIP has a long standing experience in advanced training, and offers scientific excellence, appropriate infrastructures, careful guidance and a stimulating atmosphere.

The capability to attract the best undergraduate and graduate students is central for LIP. The advanced training group was created to coordinate and promote specific actions dedicated to university students at the several levels (undergraduate, master, PhD).

LIP can offer research subjects in a range of areas, covering broadly the subject of experimental particle and astroparticle physics, but also related technologies and computing. The universities of Lisbon, Coimbra and Minho are LIP associates. In each of its three nodes, LIP works in close relation and cooperation with the local universities. The role of LIP in the training of teachers and engineers, via schools and internships at CERN, is also widely recognized.

Graduate students

LIP coordinates the IDPASC-Portugal (Particles, astrophysics and Cosmology) and DAEPHYS (applied physics and engineering) doctoral programs, as well as the IDPASC international network. Currently about 20 students are engaged in each of the programs. In 2016, both programs held summer schools. IDPASC also organized courses and workshops, including the IDPASC student workshop, in Porto. We are also a partner in two other programmes: MAPFIS, with the universities of Minho, Porto and Aveiro; and DPMPI, Physics and Mathematics for future information technologies, involving IST and several research centers.

LIP must guarantee excellent training and adequate supervision to its graduate students and assessment instruments are fundamental. In 2016, a survey was prepared and distributed to current and former PhD students at LIP. It is meant as a follow-up instrument and a tool to identify problems and propose solutions.

The first LIP's student workshop will take place early in 2017.

During 2016, LIP participated in several active ITN sponsored by the European Commission, namely the networks INFIERI, "INtelligent Fast Interconnected and Efficient Devices for Frontier Exploitation in Research and Industry" and AMVA4NewPhysics network, "Advanced MultiVariate Analysis for New Physics Searches at LHC".

The following events targeted to graduate students are foreseen:

LIP student workshop, Coimbra, 24-25 March 2017

LHC physics course, LIP-Lisboa, March to May 2017;

IDPASC student workshop, Braga, May 2017;

IDPASC international school, Asiago, Italy, June 2017;

IDPASC hands on particles and light workshop, IST and FCUL, Lisboa, July 2017;

Undergraduate students

During the Summer of 2016, LIP hosted about 40 students from IST and FCUL in internships within the ATLAS and CMS groups, and in the cosmic rays laboratory. The internships, which were diverse in model and duration, included formal training (seminars and tutorials) and the development of research projects in electronics, detector construction, computing and data analysis. In 2017, these efforts will be coordinated and a LIP summer student program will be offered. In 2017, these efforts will be coordinated and a LIP summer student program will be offered.

The following events targeted to undergraduate students are foreseen:

Particle physics mini-school, Sesimbra, Feb 2017 - co-organized by LIP and CFTP.

Careers and technology in particle physics - March 1st and 2nd, at IST and FCUL.

LIP Summer Student Programme,
July-September 2017

// CONTACTS

Mário Pimenta, pimenta@lip.pt
João Varela, joao.varela@cern.ch
Isabel Lopes, isabel@coimbra.lip.pt

Technology transfer, industry, spin-offs and societal impact

Fundamental science drives innovation in the long term, and particle physics has always been at the forefront of technology — from radiotherapy and medical physics to the Web. LIP is a key player in the application of particle physics technologies to Health, Space exploration and scientific computing. The Lab's activities provide various sets of opportunities for knowledge transfer to the economy.

Direct transfer

Direct knowledge transfer opportunities are expected across the whole spectrum of LIP's activities. In particular, applications to the health and space sectors are potential sources for the generation of new industrial property rights to be transferred to existing or new companies. In several of the medical applications groups, steps in this direction are expected in the near future. Examples of direct knowledge transfer in the 2016 activities are highlighted:

- Industrial contracts with ESA shared by LIP and Portuguese companies, namely EFACEC SA and EVOLEO SA.
- In the context of the STCD – Spin-off technology for cancer diagnosis group, LIP developed innovative electronics with good time resolution for Time-of-Flight PET. This technology was licensed to the spin-off PETsys. The activities of the group are done in coordination with PETsys. The laboratory infrastructure TagusLIP at the science park Taguspark is shared by the two entities
- In the context of the RPC R&D group, a contract was signed with the company HIDRONAV, S.A. for supplying in 2017 a 4-layer TOFtracker telescope system for container inspection by muon tomography at sea ports.
- The LIP NUC-RIA group develops technology transfer activities, namely contributions to the study of electron beam food irradiation in the framework of the International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP) devoted to the study of the effects of radiation on fresh fruits.

Finally, the LHC Phase II upgrade offers great opportunities for the participation of Portuguese industry. In 2017, the planning of the ATLAS and CMS upgrades will allow a clear definition of such opportunities. The main areas sought at present include segments of the microelectronics market, in the context of frontend readout systems for CMS subdetectors, and the replacement of the ATLAS TileCal HV distribution boards and gap/crack scintillators.

Industrial liaisons

Indirectly, LIP's involvement with CERN has triggered technological transfer to Portuguese industry through contracts awarded to Portuguese firms by CERN, in the context of its industrial procurement rules. In this respect, LIP has been operative in the coaching and in some cases in the technical support to Portuguese firms in their networking with CERN. The Portuguese Industrial Liaison Officer (ILO) is a member of LIP's staff and his activities are developed under the framework of FCT, by agreement with LIP. The ILO that is mandated to support and actively promote national industry and R&D institutions to CERN, ESO, ESRF and contribute to their success in the procurement process, thus ensuring a positive industrial return to Portugal.

Portuguese traineeship programme at CERN, ESA and ESO

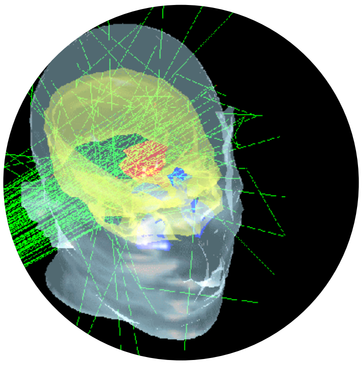
The involvement of LIP at CERN and its role in has been instrumental in FCT's engineers training programme. In 2016, LIP was directly involved in the evaluation and selection process of the trainee engineers for the Technology Internships programme at CERN, ESA and ESO. Gaspar Barreira, Director of LIP and Portuguese representative in the CERN Council, was the president of the board, which included also Pedro Abreu (LIP/IST). Five new internships started in 2016.

HEPTech network

LIP is a member of HEPTech, a unique high energy physics technology transfer network (TTN) that aims to become "the innovation access point for accelerator and detector driven research infrastructures". The network bringing together leading European high energy physics research institutions: CEA, CERN, CNRS, CIEMAT, DEMOKRITOS, DESY, ELI-ALPS, ELI BEAMLINES, EPFL, ESS, GSI, IJS, IFIN-HH, INFN, INOVACENTRUM, KTN, LIP, NTUA, SOFIA University, STFC, TU of Kosice, University of Belgrade, WEIZMANN Institute and WIGNER; which work across a range of world-leading scientific areas in the field of Particle Physics, Astrophysics and Nuclear Physics.
To push back scientific frontiers in these fields requires innovation. It is challenging and costly to carry further research and development focused in applications, products and processes and turn them into commercial opportunities. HEPTech, as a source of technology excellence and innovation, tries to bridge the gap between researchers and industry by organizing a set of activities, namely:

- Academia Industry Matching Events (AIME);
- Workshops about Technology Transfer and commercialization of research;
- Show and Tell - showcase about activities and tools related to knowledge transfer;
- Heptech Symposium - unique opportunity for early stage researchers to learn how science can impact society;

LIP, as an HEPTech node member, follows the various activities and maintains updated its awareness about knowledge and technology transfer and the paths for commercialization from fundamental research in high energy physics.



Radiation, Health and Environment

// CONTACTS

Luís Peralta, luis@lip.pt

LIP has a long standing expertise in dosimetry. R&D lines of work are combined with the provision of services to society in areas related to environmental radiation and public health.

Dose monitoring is essential to protect the patient in clinical examinations from over-exposure due to repeated exams or faults in the equipment. Researchers at LIP have develop a plastic scintillator dosimeter that could be an asset to quantify the dose in radiotherapy treatments.
Plastic scintillation dosimeters provide a low cost alternative to dose monitoring, and can be manufactured with several shapes and sizes. The work carried out with kV-CBCT beams at the Radiotherapy Service of Hospital de Santa Maria in Lisbon has shown that this type of dosimeter can be competitive with other systems for beam qualities between 100 and 120 kV.

An environmental radon survey conducted by LIP's dosimetry group, the radon concentration in water sources of public drinking of Covilhã's County was assessed. In this study 23/33 assessed samples had radon concentration levels above 100 Bq/L. Taking into account international limits, the water should be declared not safe for drinking purposes or its boiling recommended.

During 2016 the intervention in the community continue with radon air and water analyses made for two companies in Sortelha and Covilhã.

// LOOKING FORWARD

Looking forward

In this report we provided an overview of LIP's work in its main areas of activity: particle and astroparticle physics, new instruments and methods, and computing. Our main achievements in 2016 were presented, as well as the links between the lab and society: through education and outreach, advanced training, relations to industry and to society at large. Before concluding, it is now time to look into the future, unveiling what to expect in 2017.

In what concerns the LHC, last year brought a large increase in accumulated luminosity. Enough to improve the precision in many Higgs, top and W physics studies, and the sensitivity in new physics searches. In all physics analysis areas in which LIP is involved, this opened opportunities to further LIP's impact and build up our know-how. Also for the phenomenology groups, the wealth of data collected is a great opportunity to access ever more precise measurements. The consolidated network of solid competences and international collaborations and visibility should be complemented by an increase in the capability to attract students and funding.
On a slightly longer time scale, the HL-LHC/Phase II Upgrade creates opportunities for a strong participation of Portuguese industry. In 2017, the preparation of the Phase II TDR documents will provide an opportunity to consolidate and possibly expand the groups' responsibilities in the upgrade and to explore the involvement of the Portuguese industry in this effort. At the moment, such opportunities concern specifically microlelectronics in the case of CMS and HV distribution boards in the case of ATLAS.

In the structure of matter research line, the deep involvement of LIP in COMPASS and HADES will be pursued. In COMPASS, the LIP team coordinated the Drell Yan physics data reconstruction. Analyses are ongoing, and the measurement of the polarized Drell Yan process is a world first. The Drell-Yan physics programme will allow to deepen the understanding on the spin structure of the nucleon, namely the study its of transverse components. Concerning the non-polarised programme, the understanding of the quark fragmentation into hadrons can be accessed. The SPS Committee approved another year of Drell-Yan data taking in 2018 and LIP is very well positioned for a leading role.
At GSI, the accelerator infrastructure will remain inoperative during 2017, in view of its full upgrade. Nevertheless, the LIP team will guarantee the continuous operation and maintenance of the RPC TOF, keep the involvement in the construction of the new low polar angle detector and collaborated with other groups in the improvement of the performance of the upgraded detector. On the analysis side, the group will not only proceed with its involvement in the di-lepton analysis but envisage the opening of a theory-driven research line, in collaboration with theory colleagues in Portugal.

In cosmic rays, opportunities for data analysis are at present very appealing, given the impressive data sets collected by both AMS and Auger over the years, and the interesting results and puzzles that have been found. AMS remains a unique observatory in space. Exciting new results on the positron spectrum were announced, giving rise to renewed speculations on dark matter candidates and bringing AMS to the spotlight as being an extraordinary source of knowledge. Due to AMS' high exposure time and the sheer amount of data nucleon and anti-matter fluxes can now be studied with sufficient accuracy.
In Auger, the team will continue to exploit the particle physics potential of the observatory, studying hadronic interactions at the highest energies, investigating in detail the electromagnetic and muon components of air showers, and addressing the puzzle of the larger number of muons observed in air showers with respect to expectations. In parallel, the observatory upgrade will continue, together with our ambitious R&D programme based on RPC. In 2017 we will start the production of the first engineering prototypes in São Carlos, Brazil, followed by their transport and installation in Argentina. We foresee by the end of the year to have at least one full MARTA station installed and taking data.
The LATTES project stems from our previous R&D work with RPCs and proposes a detector with a large physics potential to exploit a clear window of opportunity in high-energy gamma ray studies. Currently, the priority of the LATTES international team is to develop the concept in its different dimensions, bringing it to maturity in the next five years. The Portuguese LATTES team is deeply involved in the project. Currently it holds crucial responsibilities in the development of the simulation framework and evaluation of the expected performances, as well as in detector R&D, namely RPC R&D.

Important steps forward are expected this year in the dark matter and neutrino experiments in which LIP is involved. The decommissioning of LUX has started, after obtaining a new world-leading limit for the spin independent WIMP-nucleon elastic scattering cross-section. In 2017 the work of the LIP team will already be centered in LZ. LZ is the most competitive dark matter experiment in the world, with a high potential for detecting WIMPs or setting the ultimate limit before hitting the irreducible neutrino background. The underground deployment of LZ is scheduled to begin in late 2018 and operations are expected to start in Spring 2020. In SNO+, commissioning data taking has started in late 2016. The water phase of SNO+ will be a great opportunity to use and commission the hardware and software tools we have developed, to attempt some physics measurements, and to further prepare the upcoming scintillator phases, which are expected to tart still in 2017. The recent growth of the group allows us to expand its activities and strengthen our role in calibration and backgrounds / physics analyses, and also to contribute to the event reconstruction.
The participation of LIP in NEXT stems from the concurrence of expertise and long experience both in experimental work and, specially developed Monte Carlo simulations. The systems developed are very versatile tools that can be used for a variety of studies of gaseous detectors. On a complementary approach, the possibility of a deeper involvement in this innovative experiment should be a goal for 2017.

LIP conceives and builds the particle detection instruments of the future, to be used in fundamental experiments but also in applications to Health and Space exploration. In this research line, our focus will be two-fold: on the one hand, to keep the high level of expertise we developed over the years in key technologies and, on the other hand, to actively look for opportunities which can be either specific experiments or topical application of these technologies, to solve concrete issues in a variety of related fields. The development of instruments and methods for biomedical applications stems from LIP's detectors R&D expertise. The ongoing research activities will continue to be pursued, to attain the full promise shown by existing performance results and by added value with respect to existing technologies. In the last few years, partnerships with hospitals and biomedical institutions, particularly ICNAS, represent important steps forward in the development and testing of such proposals. In 2017, the focus lies in moving further along this path, closer to clinical testing and industry. This is particularly the case of the orthogonal ray imaging (Ortho-CT) technique to improve radiotherapy treatment in near real time. It is also the case for the ANTS2 software package - a unique tool that permits to do both statistical event reconstruction and calibration of the detector response for a detector of practically arbitrary geometry. The methods and tools developed here are of interest for a large community, which represents a high potential to form new collaborations. A possible, although difficult growth of PETsys would open the possibility of research contracts between LIP and the company.

Resistive Plate Chambers (RPC) are clearly one of the specialities of LIP, with possibilities for application in a variety of contexts and domains. We now have, or are about to have very competitive detectors for market application in animal RPC-PET, muon tomography and cosmic ray physics. Important steps towards technology transfer should happen in 2017. Also, there is a widespread need for ^{3}He-free Position Sensitive Neutron Detectors with enhanced performance for applications ranging from neutron scattering science (NSS) to homeland security and well logging. The research activities at LIP are part of a wider effort within SINE2020/WP9-Detectors, aiming to develop very demanding neutron detectors, capable of performances not yet possible with present state of the art, in particular for the instruments to be installed at the ESS. Being in such international collaboration is an asset to positioning LIP in what will be the center of neutron detector development needs in the coming decades.
Gaseous and Xenon based detectors are another of the long standing specialities of LIP. The ongoing R&D projects in this area can provide a valuable input for future large scale detector development. Ion mobility measurements eagerly needed by the community have recently been carried out with success. There is a serious possibility of expanding our work to the Astrophysics domain, where new gas mixtures for polarimetric studies are being sought. Such opportunities will be explored in 2017.

LIP's Experimental Nuclear Astrophysics group participates in the R3B collaboration of the future FAIR facility at GSI. In 2017, the group will continue this involvement in R3B and consolidate its participation in ISOLDE at CERN. The LIP group is officially involved in the ISOLDE planned 2017 experimental runs.The participation in the consortium ENSAR2 of Horizon2020 allows the participation and active involvement in nuclear reaction experiments performed in radioactive and stable ion beam facilities in Europe until 2020. The ChETEC COST activity also opens a spectrum of opportunities in the field of Nuclear Astrophysics.

Space applications is another research line stemming from LIP's expertise in radiation detection and process simulation. The participation in ESA missions, ESA contracts and European Union funded H2020 programmes, together with the recent growth of the teams, makes this research line a rather active one, and LIP a recognized partner of ESA. Highlights for 2017 surely include the participation in the preparation of JUICE, ESA's future mission to the Jovian system, and the expected ESA decisions on XIPE (X-ray mission Polarimetry Explorer, one of three pre-selected missions) and on e-ASTROGAM (ESA M5 call).

The LIP distributed computing and digital infrastructure activities encompass the support for scientific research through the provisioning of computing and support services, complemented by a component of innovation, aimed at staying at the forefront of computing technologies. In 2017 our work will continue to focus on the operation and improvement of LIP's computing services, the participation in the Worldwide LHC Computing Grid (WLCG), European H2020 projects, and in the national and international initiatives: National Distributed Computing Infrastructure (INCD), European Grid Infrastructure (EGI) and Iberian Grid Infrastructure (IBERGRID). In 2017, all the necessary steps for the migration of LIP Lisbon to new premises will be undertaken.
Looking further into the future, opportunities include to use the strategic know-how accumulated over the last 10 years to maintain and improve LIP's computing infrastructure in partnership with FCCN and LNEC, to consolidate and optimize scientific computing resources distributed across several organizations under a single, well defined infrastructure, and to enable future policies for scientific computing by creating a structure for the sharing and open access to publicly funded computing capacity.
A proposal to fund the Portuguese National Distributed Computing Infrastrcture (INCD) was approved early in 2017 for a three years period. This is a partnership led by LIP, LNEC and FCCN. In the first year the operational and management structure will be established. The technical focus will be put in the improvement of the INCD IaaS cloud housed at INCD. The IaaS cloud now being delivered as a beta service will continue to support the current user base. R&D for new services to be provisioned on top of the IaaS layer is also foreseen.

At LIP-Minho, the local group will continue to give support, to collaborate on the optimization of data analysis codes, and to administrate a small flexible Tier 3 HPC Cluster.

LIP's scientific infrastructures are central in the laboratory's activities. The recent revision of their management and working procedures should ensure in 2017 and improved capability to answers to internal and external requests. Along the same rationale, the first competence center at LIP, the "Simulation and

Big Data" center, will become operational during 2017. During this year, the idea should grow and more competence centers should be established, for example on detector technologies.

New premises for LIP in Lisbon have been contracted with the Lisbon University, doubling the available area and providing adequate laboratory space. In Coimbra, the University made available a new area for the expansion of the mechanical workshop and of the detectors laboratory and, in Braga, the University announced that a new area for LIP-Minho will be available soon. At, IST, in Lisbon, a "control room" for remote CMS and Auger shifts will introduce students to the environment of experimental particle and astroparticle physics. This means in 2017 we will have, for the first time, appropriated conditions for research and teaching laboratories, which will open a wide range of possibilities for training offers for undergraduate students. These upgrades should also boost our possibilities to design and construct hardware for educational demonstrations and experiments, in the line of the LIP spark and cloud chambers.

Hence LIP's opportunities for science outreach and advanced training will be boosted. The activity in this area during the past year as already began to pay off. More students are aware of the training possibilities we offer, our impact and our links with local universities are growing. Our engagement with schools and the society at large continues to motivate us and to introduce more children and adults to the wonders of particle physics and of science in general.

Let us conclude by noting how the links of LIP to society are getting always stronger — from university students to the national scientific community, from schools to the society at large. In 2017 LIP is moving forward, facing new challenges and opportunities!

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