ANNUAL REPORT

2019/2020

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

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ABOUT LIP

INTRODUCING LIP

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

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

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

The three pillars of activity at LIP are:

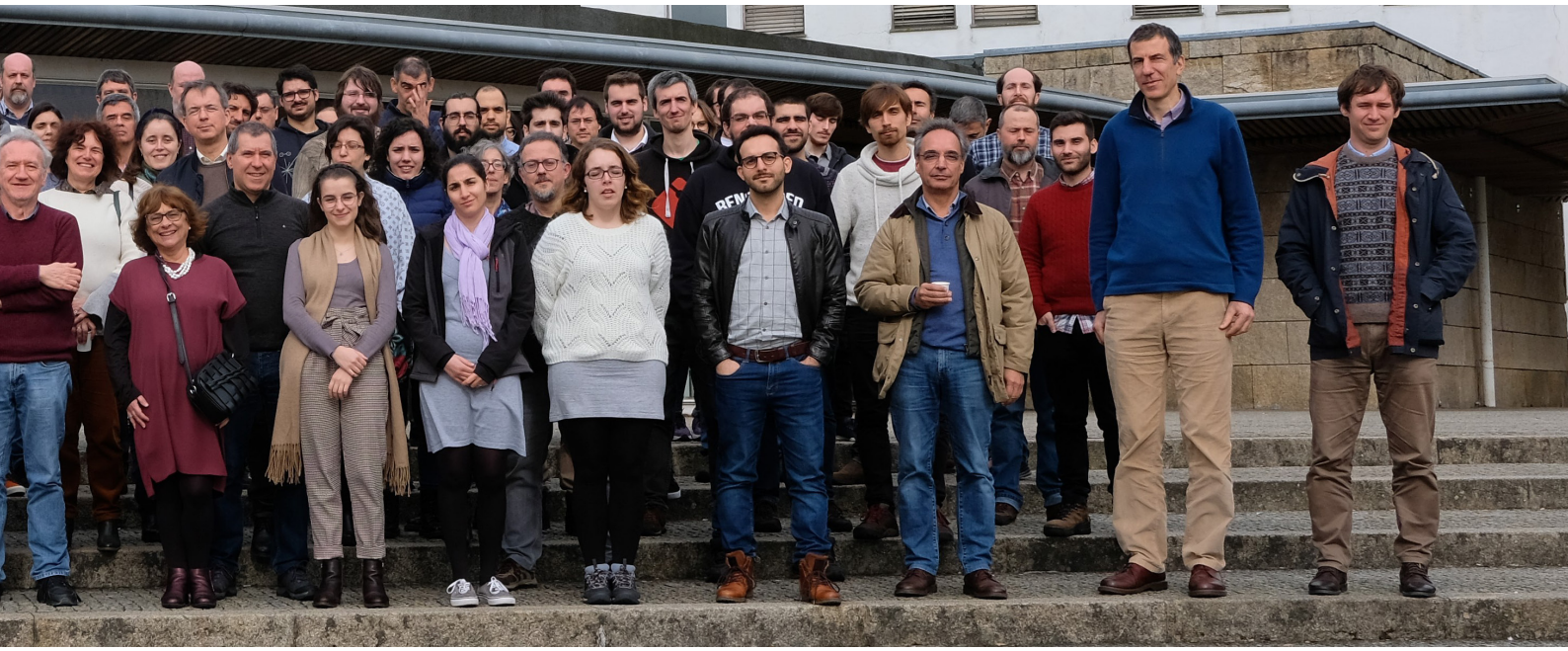
- **Discovery through science:** LIP's programme of experimental particle and astroparticle physics is international, has world-class quality and addresses some of the most topical questions of our time.
- **Innovation through technology:** basic science drives innovation in the long term. LIP is a key player in the application of particle physics technologies to health care and space exploration, and in scientific computing.
- **Sharing with people:** LIP works to engage society in science, to inspire the younger generations to pursue careers in science and technology, and to address societal challenges through science.

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

- **Experimental particle and astroparticle physics;**
- **Development of new instruments and methods;**
- **Scientific computing.**

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

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



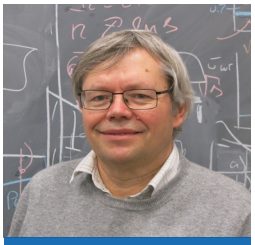
strong expertise in other gaseous detectors, scintillator/fibres calorimetry, and fast electronics for data acquisition systems. Specific R&D lines are dedicated to health care and space exploration applications.

Computing is certainly one of the areas placing LIP at the forefront of innovation. The LIP Computing Groups have extensive knowledge and experience in scientific computing, focusing on Grid and Cloud technologies. They have excellent international relations and integration in the main R&D projects and scientific e-infrastructures, with users from multiple organizations and disciplines. LIP co-leads the National Infrastructure for Distributed Computing, participating in the enabling of future policies for scientific computing and open access, and serving the Portuguese scientific community at large. The fast growing expertise in data science and big data in the laboratory creates the potential for engaging with other communities in addressing a number of societal challenges.

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

DIRECTORATE'S REPORT

Challenges and Responsibilities



prof.
Mário Pimenta
President

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

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

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

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

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

New groups have recently joined LIP. In December 2019, the IST Theoretical Nuclear Physics group joined and became the NPstrong (Nuclear Physics and Strong hadronic interactions) LIP Group. LIP has now the largest Nuclear Physics group in Portugal and thus must be a reference also in this scientific area. The synergies with many other LIP groups are evident: from phenomenology to the neutrinos and dark matter experiments; from medical physics to space applications.

Already this year, in February 2020, the Social Physics and Complexity Group (SPAC) joined LIP. It is a small but very active group with strong synergies with the Computing Group and the Competence Centre in Simulation and Big Data. Interactions with other LIP groups, as for instance the Phenomenology Group, may reveal very fruitful. This group enlarges and enriches LIP's scientific and societal intervention areas.

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

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

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

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

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

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

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

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

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

LIP Scientific Infrastructures are essential for LIP's activity. Re-equipment funds for the Detectors Laboratory (DL) in Coimbra and for the Cosmic Ray Electronic Laboratory (e-CRLab) and the Laboratory of Optics and Scintillating Materials (LOMaC) were assigned as a result of the evaluation of the Portuguese research units. In the DL, the main investment will be in the installation, in the coming months, of a ISO6 clean room. Together with the recent acquisition of a new CNC machine, this will strongly enhance the gaseous detectors building capabilities, including possible opportunities of high-valued external commissions. The investment in the e-CRLab will allow to work in the GHz range (ns), improve the capability to work outdoors and create new working positions at LIP. By a collaboration with the LIP ATLAS group, the e-CRLab will be responsible for some of the tasks foreseen in the Portuguese participation in the ATLAS detector upgrade program. In this framework, a new technician will be hired and new opportunities for students will exist.

Students are essential for maintaining the vitality of any research institution, and LIP is no exception. Since long, particular attention is given to the promotion of advanced training opportunities for students, that are both top level and broad in field, namely in the framework of IDPASC (Particles Astrophysics and Cosmology) network. The recently created LIP Student Council will for sure contribute to boost the participation of students in the organization of new activities, contributing to further improve the quality of PhD and master students hosting and training at LIP.

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

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

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

(Mário Pimenta)
Lisbon, March 2020

Report from the International Advisory Committee

Sergio Bertolucci (former Director of Research and Scientific Computing at CERN), Eamonn Daly (former Head of Space Environment and Effects Section of ESA), Katia Parodi (Medical Physics Chair at LMU, Munich), Pier Giorgio Innocenti (former CERN ECP Division Leader), Christian W. Fabjan (Austrian Academy of Sciences), Luigi Rolandi (Scuola Normale Superiore - Pisa), Masahiro Teshima (Director of the Max Planck Institute of Physics)

The LIP International Advisory Committee and representatives of LIP held their annual meeting on 15th and 16th April 2020 via a teleconference, a consequence of the Covid-19 pandemic restrictions. Prior to the meeting, theCommittee had received extensive and well-prepared documentation about the LIP activities. Oral presentations and discussions during the meeting provided further clarifying information.

This meeting followed an in-depth review by the International FCT Evaluation Panel, June 2019, attesting LIP the rating "Excellence".

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

In parallel, LIP maintains a strong programme directed at future activities. LIP teams are progressing with R&D, design and prototyping for the High-Luminosity LHC upgrade of ATLAS and CMS. R&D, design and prototyping are also pursued for the DUNE neutrino experiment in preparation in the USA. LIP is among the proponents of the new SHiP facility at CERN, searching for weakly interacting long-lived particles and studying neutrino physics. LIP is a key promoter of SWGO, a novel ground-based array in the Southern hemisphere for high-energy gamma ray astronomy.

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

LIP is maintaining its outstanding leadership in scientific computing, both within Portugal and internationally. Software developments, advanced algorithms and techniques and an excellent record of system management, performance and availability have made LIP the leader in the deployment and operation of the Portuguese scientific computing infrastructure and a most welcome partner in many international projects. The LIP computing teams are engaged in many important international collaborations and have again steadily progressed during 2019.

LIP is growing, in line with its mission to federate institutions and groups with activities related to LIP. During the past few years, the joining of new groups strengthened areas such as theoretical and nuclear physics and computing. Very recently, the group

"Societal Physics and Complexity" joined, bringing to LIP stimulating new competences. The Committee strongly supports this strategy, which will be fruitful beyond LIP for the scientific life in Portugal.

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

As noted previously, the remarkably diverse and multi-faceted research and R&D activities carry a certain risk of fragmentation. The LIP Leadership is fully aware of this risk and continues their efforts in sharpening the focus. One example concerns the many R&D efforts in medical instrumentation, where streamlining and clarifying LIP's strategy should be undertaken. These activities should also be aligned with the programme at the planned center for tumor therapy with proton beams.
The Committee applauds and encourages the LIP Management to pursue vigorously these several lines of convergence.

The Committee was pleased to learn that the employment perspectives at LIP continue to improve. In line with LIP's healthy agenda, aiming at growth, LIP plans to increase its staff by more than 20% over the next five years. The Committee strongly supports this strategy. Implementing it will require a clearly defined roadmap for LIP's development over the coming five to ten years, critical internal reviews prioritizing activities, as well as documenting the need for each new position. Part of the strategy, in the view of the Committee, must also be a reasonable balance between baseline and project-related funds to cover staff expenses.

The recently established Portugal-CERN Ph.D. programme will provide 15 new positions per year. This is a most valuable addition to the research staff, requiring proper supervision of the students. Some level of supervision and mentoring of the supervisors may also be necessary. Steps in this direction should be intensified.
The recently established new management structure has proven to be effective. Notable achievements are the improved coordination among groups active in neighboring fields of research. The very successful Competence Centers are another fine example of leveraging the staff's competences.

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

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

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

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

Report from FCT Evaluation

Panel: EXACT SCIENCES - Physics

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

Overall Quality Grade: EXCELLENT

Evaluation Criteria Ratings

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

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

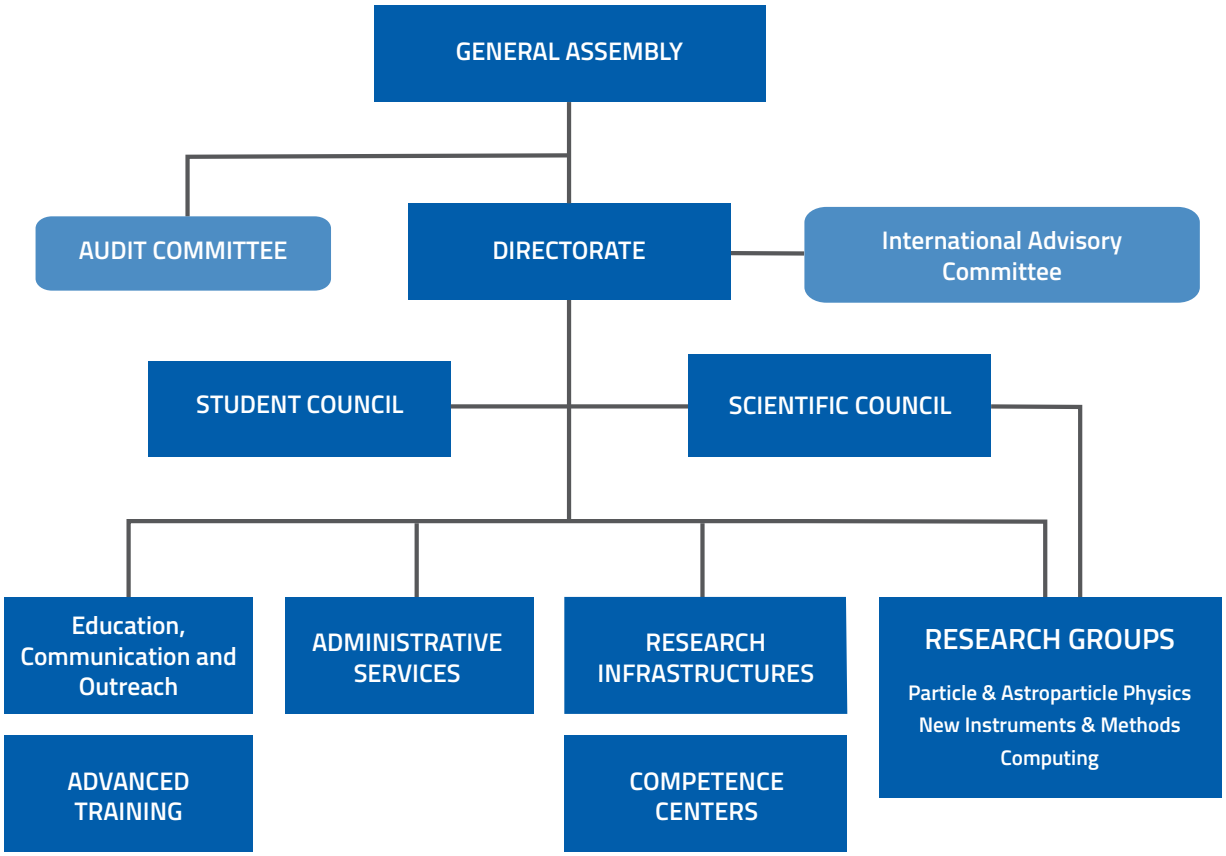
(C) Appropriateness of objectives, strategy, plan of activities and organization: 5

Justification, Comments and Recommendations

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

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

Structure and governance



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

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

General Assembly

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

International Advisory Committee

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

Audit Committee

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

Directorate

LIP is governed by a Board of Directors nominated by its General Assembly, after consultation of LIP members. The different nodes of LIP are represented in the Board of Directors, which meets on a monthly basis and issues brief reports of its deliberations to the scientific council. At present the national directorate is formed

by Mário Pimenta (president), Isabel Lopes, Nuno Castro, Patrícia Gonçalves and Rui Ferreira Marques.

Scientific Council

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

Student Council

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

The main elements of the working structure of LIP are:

Research Areas, Lines and Groups

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

Research Infrastructures

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

Competence Centres

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

Administrative services

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

Advanced training office

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

Education, Communications and Outreach office (LIP-ECO)

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

Highlights of the year

January 2019

- SNO+ Collaboration publishes its first results
- 1st general meeting of the BigDataHEP project, Coimbra
- Two thousand optical fibres for the ATLAS upgrade prepared at LOMaC lab were shipped to Michigan State University

February

- International Day of Women and Girls in Science: "Particles: from the universe to the lab", a public session led by LIP PhD and master students
- 4th LIP-CFTP mini-school on Particle and Astroparticle Physics
- The Detectors Lab completed the production of the 42 RPCs for MARTA, passing the line of the 100 sensitive volumes produced
- The LIP computing group is in the new H2020 project EOSC-synergy

March

- The world celebrated the 30 years since the birth of the World Wide Web at CERN
- Start of the 2019 IPPOG Masterclasses in Particle Physics in Portugal
- Mariana Araújo, PhD student in the LIP CMS group, received the Maria de Lourdes Pintassilgo Prize of IST in the Young alumni category, "in recognition of her exemplary academic path"
- LIP is part of STRONG-2020, a new 10M€ European project for the theoretical and experimental study of strong interactions
- 2nd LIP Data Science School and Symposium, Braga
- ERC Advanced Grant YoctoLHC, led by Carlos Salgado (Univ Santiago de Compostela/IGFAE) awarded, and LIP is part of the team

April

- HiRezBrainPET, a project for the development of an innovative PET scanner based on Resistive Plate Chambers (RPC-PET) approved
- CERN celebrated the 40 years of Physics in the SPS NA

May

- National Scientific Computing Days, Azores
- European Particle Physics Strategy discussed in Granada
- The second URM for SNO+ calibration built at LIP's Workshop and Detectors Lab shipped to SNOLAB
- LHCP2019: the LHC physics conference
- 1st Biophysics Collaboration meeting at GSI
- Celebration of 100 years of Eddington´s observations in Príncipe

June

- LIP was considered "Excellent" in FCT's evaluation of the R&D units in Portugal
- 16th edition of the International Workshop on Hadron Structure and Spectroscopy, Aveiro, Portugal, co-organized by LIP
- COMPASS Collaboration Meeting at the University of Aveiro, Portugal

July

- SWGO: An international collaboration was launched for a new gamma-ray observatory in the southern hemisphere
- 2019 LIP/IDPASC PhD Students Workshop, Braga
- Opening of the MACC - Minho Advanced Computing Centre
- National Science meeting "Ciência 2019", Lisbon
- Start of the 2019 edition of the LIP Internship Program

August

- HEP conference of the European Physics Society 2019, Ghent, Belgium
- International Cosmic Ray Conference 2019, Madison, USA
- HADES in Nature Physics, with direct contribution from LIP in the analysis
- LIP adheres to the Charter of Principles on Gender Equality - SAGE Project

September

- Visit to CERN of the Minister of Science, the President of FCT and the Secretary of State for Internationalisation, accompanied by the LIP Directorate and researchers
- Portuguese-speaking physics teachers Program at CERN
- 3rd LIP summer internship workshop
- Tribute to Gaspar Barreira, Rectory of the University of Lisbon
- LIP at the European Researchers Night, in Braga, Coimbra and Lisboa
- IBERGRID 2019 Conference, Santiago de Compostela, Spain

October

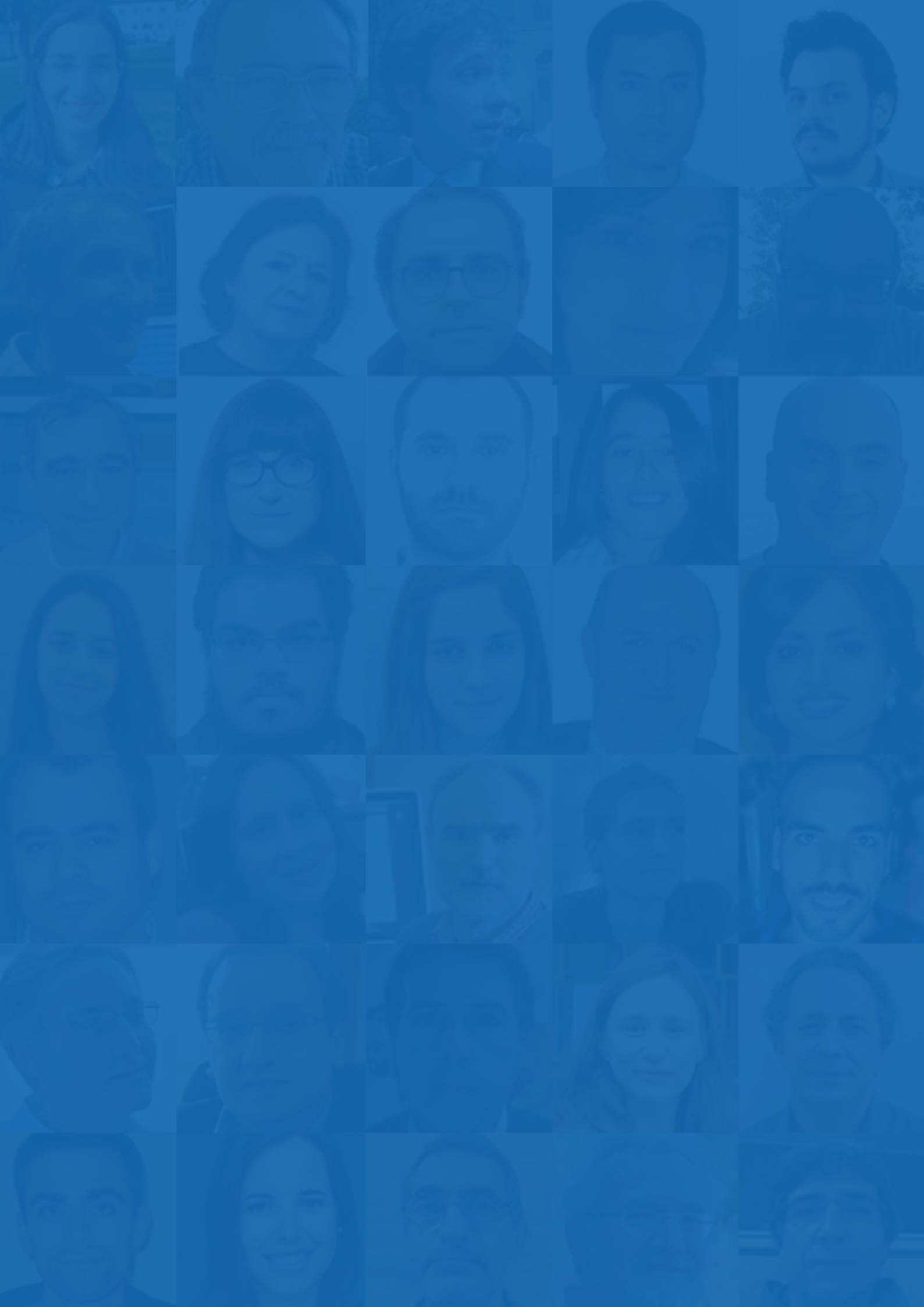
- 2nd International Workshop on Soft X-ray single order diffraction grating: development and applications, University of Coimbra, co-organized by LIP
- LZ collaboration successfully transports the central part of its detector to the underground SURF laboratory, 1500 m deep

November

- The Cygnus spacecraft carries to the ISS the new cooling system for the AMS inner tracker
- Quark Matter 2019, China
- Celebration of the 20 years of the foundation of the Pierre Auger Observatory
- National S&T Week
- Award ceremony of the European Prize Helena Vaz da Silva to Fabiola Gianotti, in Lisbon

December

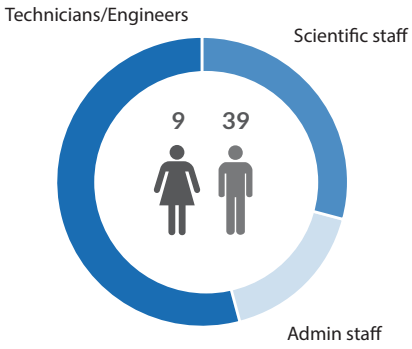
- The Portuguese Proton-Therapy and Advanced Technologies for Cancer Prevention and Treatment Association (ProtoTera) was formally created
- Beyond the Standard Model workshop, Lisbon, in the context of the VBScan COST Action
- Assembly and installation of a large part of the CALIFA detector at FAIR
- Agreement between LIP and FCT for the new Portugal-CERN PhD grant programme



LIP IN NUMBERS

HUMAN RESOURCES

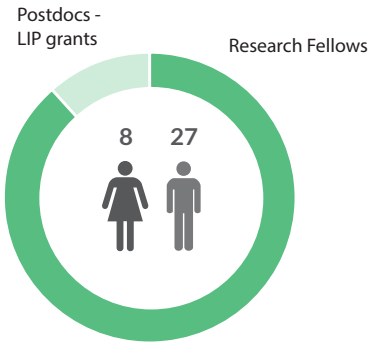
STAFF



= 48 TOTAL

Technicians/ Engineers	0	26
Scientific staff	2	12
Admin staff	7	1

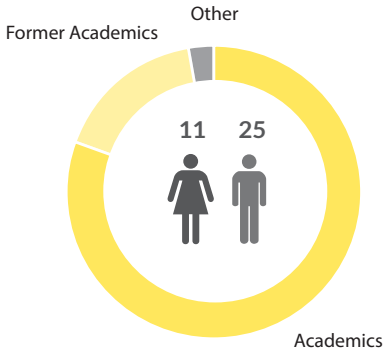
FIXED-TERM RESEARCHERS



= 35 TOTAL

Research Fellows	6	25
Postdocs LIP grants	2	2
Postdocs other grants	0	0

UNPAID



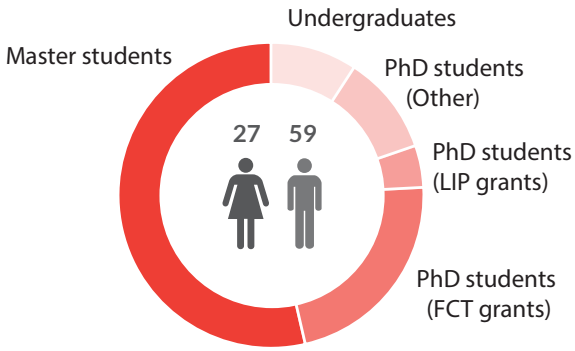
= 36 TOTAL

Academics	7	22
Former Academics	4	2
Other	0	1

TOTAL 205

55 150

STUDENTS

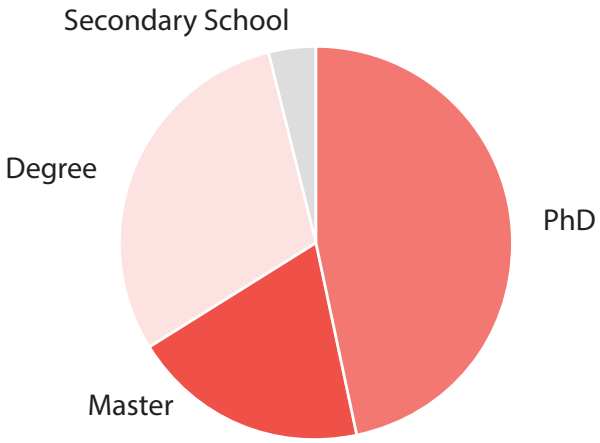


=

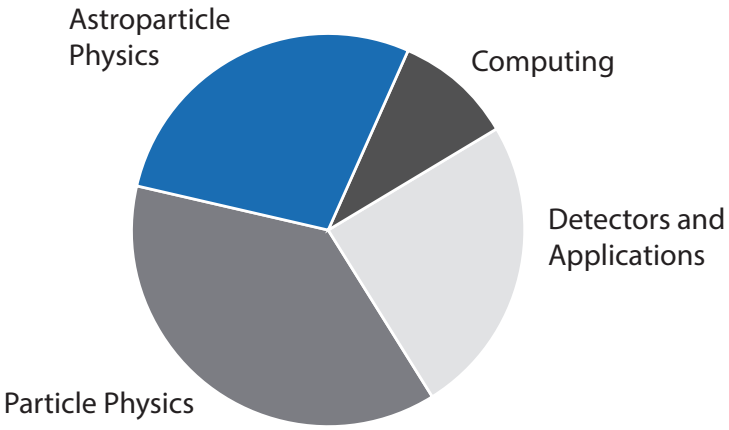
86
TOTAL

Master students	13	33
PhD students FCT grants	7	12
PhD students LIP grants	0	4
PhD students Other	4	5
Undergraduates	3	5

DISTRIBUTION BY ACADEMIC QUALIFICATION

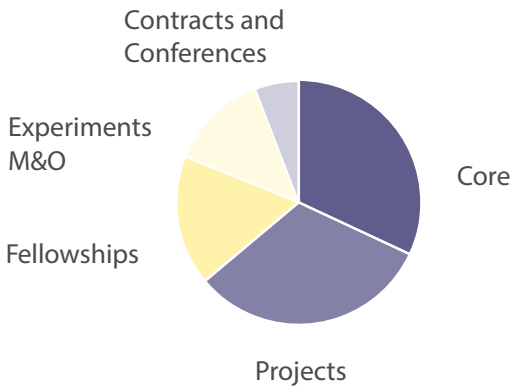


DISTRIBUTION BY RESEARCH AREA



FINANCES

GENERAL FUNDING



1.7M
CORE FUNDING

1.7M
PROJECT-BASED

0.9M
FELLOWSHIPS

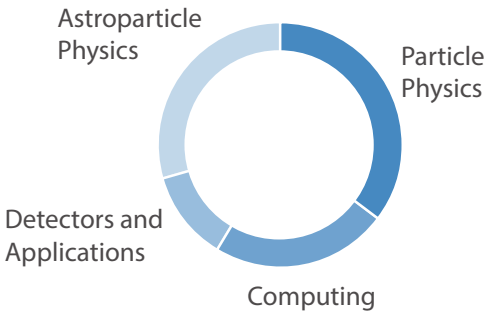
0.7M
EXPERIMENTS M&O

0.3M
CONTRACTS AND CONFERENCES

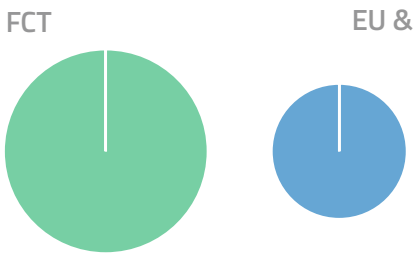
TOTAL
5.3M €

PROJECT AND CONTRACT-BASED FUNDING

BY RESEARCH AREA

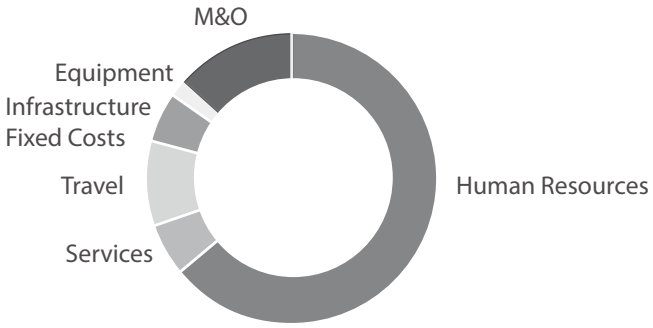


BY ORIGIN



TOTAL
1.7M €

COSTS



HUMAN RESOURCES

STAFF 1.9M

FIXED-TERM RESEARCHERS 1.5M

SERVICES AND OTHER EXPENSES

0.3M

TRAVEL

0.5M

EXPERIMENTS M&O

0.7M

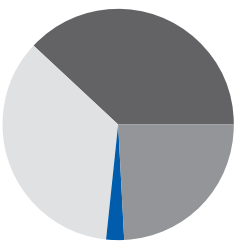
INFRASTRUCTURE FIXED COSTS

0.3M

EQUIPMENT

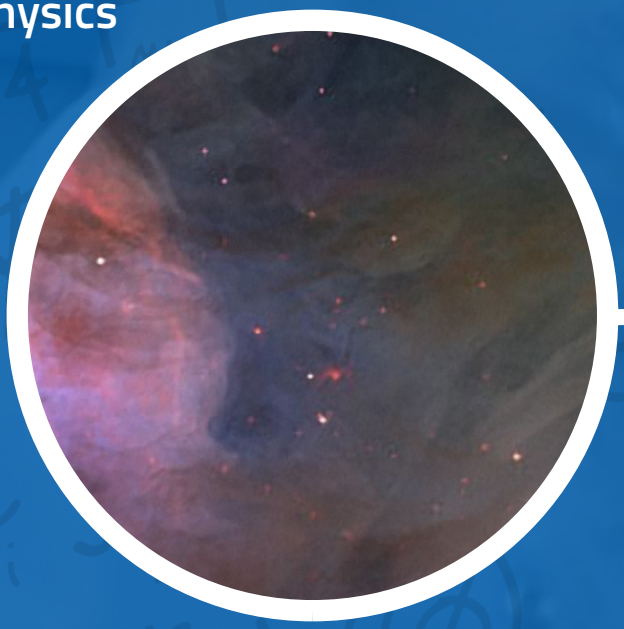
0.1M

SCIENTIFIC OUTPUT 2019

		Particle Physics	Astroparticle Physics
Books, Reports and Proposals		7	0
PhD Theses		2	0
Master Theses		7	2
Proceedings		17	13
Notes		22	10
Presentations		130	66
Papers in refereed journals		250	25

Detectors and Applications	Computing	TOTAL
2	0	**9**
2	0	**4**
7	1	**17**
13	3	**46**
4	12	**48**
74	20	**290**
19	1	**295**

Experimental particle and astroparticle physics



RESEARCH AT LIP

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

Computing

Experimental particle and astroparticle physics

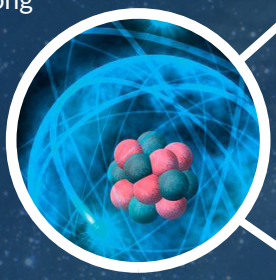
Development of new instruments and methods

LHC experiments and phenomenology

- ATLAS
- CMS
- Pheno

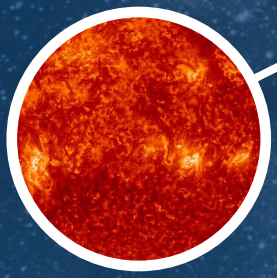
Structure of matter

- pQCD
- HADES
- NUC-RIA
- NPstrong



Cosmic rays

- AMS
- Auger
- LATTES



Dark matter and neutrinos

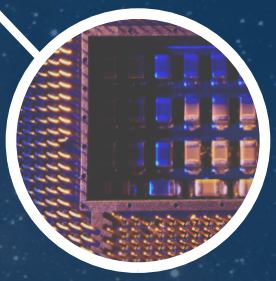
- DARK MATTER
- NEUTRINO
- SHiP

RESEARCH

Computing

Detectors for particle and nuclear physics

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

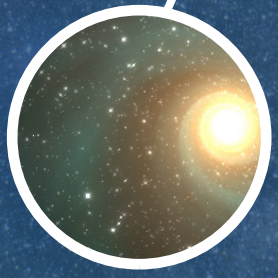


Scientific computing

- Distributed Computing and Digital Infrastructures
- Advanced Computing
- Social Physics and Complexity

Health and biomedical applications

- OR Imaging
- Gamma Cameras
- Dosimetry



Space applications

- Space Rad
- i-Astro

Experimental particle and astroparticle physics

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

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

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

We still have a lot to learn about how quarks and gluons work together to form the particles we observe. That is the focus of our structure of matter line of research. The Partons and QCD (PQCD) group is currently involved in studying hadron structure with the COMPASS experiment, and in preparing the next steps of CERN's fixed target experimental programme, namely the AMBER proposal; LIP has the only Portuguese experimental team preparing to explore the frontier between nuclear and particle physics at the new FAIR facility at the GSI, and is deeply involved in the HADES and R3B experiments. The NPstrong group has just joined LIP and will bring remarkable theoretical consistency to this research line, as well as opportunities for collaborations between different LIP groups.

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

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

EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

LHC experiments and phenomenology

Physics at the energy frontier

With the LHC Run 2 completed in 2018 and the upcoming Run 3 starting in 2021, the past year was used to digest the accumulated data and to prepare for the future. The ATLAS and CMS experiments have each collected collision datasets that could only be dreamt of a few years ago. Run 2 data have already led to several important publications, with several more currently being completed or reviewed by the collaborations. The ATLAS, CMS, and Phenomenology groups at LIP have been deeply involved in the exploration of the unique LHC data, as well as in LHC upgrades. During the past year, the Phenomenology group has also expanded and fully consolidated, with work already filtering into some of the experimental analyses where LIP is involved. Other internal synergies have been strengthening this area, for example with the Big Data competence centre, where machine-learning techniques are being exploited to improve the sensitivity of experimental and phenomenological analyses. A major milestone of the LHC upgrade Phase 1 will be achieved soon, with the commissioning of CERN's new linear accelerator, LINAC4, as the first stage of the future LHC accelerator chain. The experiments are also being upgraded to cope with the increased rate of collisions. ATLAS and CMS teams at LIP were deeply involved in the Phase 1 upgrade of the detectors, and their work was completed in the past year. At the same time, the Portuguese participation in the LHC Phase 2 upgrade was confirmed by a Memorandum of Understanding signed by the Portuguese funding agency FCT, and both teams have ramped up their work on this challenging and exciting project. It will provide the detectors with vastly enhanced capabilities, for the optimal physics exploitation during the High-Luminosity LHC phase (HL-LHC). On the accelerator side, an important milestone was reached last year, with the successful test of a 11-Tesla Nb_3Sn superconducting dipole magnet. The new sub-detectors and upgrades will be installed during the long shutdown from 2025 to 2027, and the HL-LHC commissioning will start at the end of 2027. Finally, the LHC groups at LIP were deeply involved in studies to inform the next update of the European Strategy for Particle Physics, which will soon be voted by the CERN Council. This important document is the product of more than a year of reflection and debate by the whole community, and will define the global priorities in this field for years to come.

The Higgs Boson: a microscope to search for new physics

Our last annual report described 2018 as the year of Yukawa interactions. This is because ATLAS and CMS have both observed the long-awaited interactions of the Higgs boson with the heaviest quarks: b and top. In the past year, the ATLAS team has already started to use these interactions as a tool to probe beyond our current understanding of particle physics. They focus on Higgs bosons decaying to a pair of b quarks, in both the associated production of the Higgs boson with a W or a Z boson, and with a top-quark pair (ttH). This allows them to study the direct interaction between Higgs and heavy quarks, the least studied of the Higgs sector. The focus of these analyses, currently being reviewed by the collaboration, is the accurate measurement of the Higgs boson properties. If deviations from the theoretical expectations described by the Standard Model (SM) are found, the detailed study of these properties may have far-reaching implications. Possibilities include an indication that the fundamental CP symmetry is violated in Higgs processes, which could help to explain why the Universe is composed of matter, largely dominating the existing antimatter. Getting enough sensitivity to reach clear conclusions will be a long and challenging process, but this process has now started.

The CMS team has also focused on the Higgs as a window to physics beyond the SM. They developed machine-learning tools to increase the experimental sensitivity to the production of Higgs boson pairs, decaying to pairs of tau leptons and b quarks. Observing di-Higgs production is the ultimate LHC goal in the Higgs sector, as it can uncover precious information about the shape of the Higgs potential, which lies at the heart of electroweak symmetry breaking. But it will be a very challenging task, which may only be achieved at the end of the HL-LHC experimental programme. To make progress in this task will take all the ingenuity of researchers, and all the tools at our disposal.

This experimental work has been complemented by studies in the Phenomenology group. A variety of scenarios were investigated, including extended Higgs sectors, their implications on astrophysical measurements, the low-energy signatures of new light scalars, but also the reach of experimental analyses at the HL-LHC and a possible Future Circular Collider.

Top: the heaviest weight

The LHC is a top quark factory, providing the best opportunity for detailed measurements of this heaviest of fundamental particles. Top physics has for long been a particular speciality of LIP's ATLAS, CMS and Phenomenology groups. The CMS team has had a leading role in the analysis of LHC Run 2 measurement of the top-quark pair production cross section,

with the top quark decaying to tau leptons. The group is also pursuing a search for top-quark pairs (and also W boson pairs) through two-photon exclusive processes, only made possible through the use of the Precision Proton Spectrometer (PPS), located very close to the LHC beam. The huge mass of the top quark makes it a likely window to observe subtle effects of new physics, not described by the SM. The ATLAS team is playing a leading role in the effective field theory interpretation of top quark measurements. These will use the wealth of top--physics results produced at the LHC to constrain the possible forms of underlying new physics theories that may be at the basis of the SM. First results of this analysis have been produced and are currently being reviewed by the collaboration.

Illuminating Dark Matter

LHC experiments are actively searching for a particle capable of explaining the mysterious Dark Matter, which is known to exist through astrophysical data. On the ATLAS side, the LIP team led the analysis of events where a top quark is produced together with a large missing transverse energy. This missing energy is a signature for weakly interacting particles, such as neutrinos, which escape detection. But it may also indicate the presence of a dark-matter particle, as these must interact very weakly with normal matter. Their results are included in an article documenting the combination of dark matter searches in ATLAS. The CMS team, on the other hand, has focused on proton collisions where a Higgs boson is produced together with the large missing transverse energy signature. The existence of dark matter is known through its gravitational interaction, indicating that it must possess a mass. It is therefore expectable that dark-matter particles interact with the Higgs boson, and so may be produced together with it. Such an observation would be a major step forward.

A Supersymmetric Universe

In supersymmetry, or SUSY, each known particle is expected to have a mysterious twin, with a different spin quantum number. The spectrum of these supersymmetric particles (or sparticles for short) could include the perfect candidate to explain the dark matter, for example, and so could outnumber the known particles by a large factor in the present-day Universe. But showing that this theory is realized in Nature has so far proved a difficult task. This is one of the areas where the CMS group at LIP has much experience. In the past year, the group has presented their Run 1 search for a light supersymmetric top quark partner, or stop, at the main SUSY yearly conference, and initiated analysis of Run 2 data in the quest for this particle. Their search for a tau lepton partner, a stau, was also published.

Expect the unexpected: Exotic Physics

The ATLAS team has been developing a strong expertise in direct searches for new phenomena. One focus has been the production of heavy vector-like quarks (T or B), whose existence would account for the unexpectedly low value of the Higgs mass, one of the lingering mysteries in this area. They have led the Run 2 search for T and B quarks in the Zt/b+X channel, currently under collaboration review. To separate the small signal from an overwhelming background, it exploits the regime where vector-like quarks are highly energetic, and uses deep-learning techniques. In addition, the team has a long-term dedication to the study of Flavour-Changing Neutral Currents.

The Force is Strong

The CMS team has important expertise in the measurement of rare decays, and was involved in the observation of the extremely rare $B_s^0 \to \mu^+\mu^-$ meson decay in Run 1. The team has continued to contribute to the analysis of this channel with Run 2 data, and has performed associated measurements of the *b*--quark fragmentation-fraction ratios. A combined result of Run1 and 2016 data has been submitted for publication. The team has also delivered the sensitivity projections of the $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ analyses for the high-luminosity phase of the LHC.

The Phenomenology group has published a tour-de-force calculation of the triple-differential cross section for di-jet production, describing this process as a function of average jet transverse momentum, rapidity and jet angular separation. This calculation was performed for the first time including second-order perturbative QCD corrections, and will allow a step up in the precision of LHC experimental measurements.

Phenomenological studies of quarkonia, to better understand the mechanisms of hadron formation in QCD, have been pursued in collaboration between the CMS and Phenomenology groups. In 2017, the team had uncovered that the existing LHC quarkonium production measurements show all quarkonium states following a universal scaling pattern. This observation provides powerful guidance for studies in this area. The CMS group has contributed to the very first measurement of the polarization of χ_c states, now submitted for publication.

The Hot Universe – Hadronic Matter and Heavy Ion Physics

The LHC provides unique opportunities to study heavy-ion collisions and observe the Quark Gluon Plasma (QGP), which existed in the hot and dense medium of the very early the Universe. The ATLAS and CMS groups are exploring the characteristics of QGP using different probes, both based on the behaviour of the heavy b quark as it crosses the QGP medium. ATLAS focuses on the use of hadronic jets initiated by heavy quarks, and has been developing *b*-tagging algorithms adapted to this difficult environment. The CMS team, on the other hand, has concentrated on the identification and measurement of b-quark hadrons, and has reported the first observations of B mesons in nuclear collisions: after B^+ also B^0_s and B^0. This work is very well matched to the expertise in the Phenomenology group. Several aspects of the interaction of quarks and gluons as they traverse the QGP medium were studied: from a unified model of jet and hadron suppression, to the kinematics of parton splitting in the medium, or a new analysis method for the modifications induced by the QGP on the jet substructure.

Tools of the trade - Detector Upgrades

In addition to the physics analysis activity during 2019, the ATLAS and CMS teams at LIP have worked on their experi-

mental tools, both on hardware and event reconstruction, and ramped up their activities in the upgrade of each experiment.

The ATLAS team coordinates the maintenance, operation and upgrade of the Detector Control System (DCS) of the TileCal calorimeter and forward detectors, as well as the TileCal calibration. The CMS team coordinates the proton reconstruction activity of the PPS spectrometer, and is also involved in the alignment and high-level trigger of this detector. They have also contributed to the validation of the tau lepton reconstruction in CMS.

The LHC is scheduled to resume operation in 2021, with around twice the current luminosity, or rate of interesting collisions. A second phase, known as High-Luminosity LHC (HL-LHC), will start in 2027 with even higher luminosity, with the goal of collecting some 20 times more data than has been accumulated so far. Both ATLAS and CMS teams at LIP have made crucial contributions to their respective experiment and are involved in their upgrades.

In 2019 the LIP CMS group continued its R&D activity on the front-end readout system of the Barrel Timing Layer, which is the full responsibility of LIP. This system is based on a fast timing TOF ASIC provided by Portuguese industry. LIP takes responsibility for the design, production and testing of the 1900 frontend boards for this detector. The first prototype readout unit was designed and fabricated, and currently under tests. The team has also continued the development of the new electromagnetic calorimeter readout system, based on a fast amplifier and a new, fast and low power analog to digital converter (ADC). The first ADC design was integrated in a chip with additional digital logic and data transmission, and was tested towards the end of 2019. The CMS group is also involved in the development with Portuguese industry of a new low voltage regulator, resistant to radiation, for the new High-Granularity Calorimeter that will completely replace the current electromagnetic calorimeter end-caps. In addition, machine-learning algorithms to discriminate pileup background using this detector have been developed, with a view to include them in the first trigger level.

The ATLAS team is deeply involved in the Phase 2 upgrade of two major detector systems: the TileCal and the Trigger and Data Acquisition (TDAQ) upgrade, where its DCS expertise will also be extremely important.. In 2019 the ATLAS team has completed its involvement in the Phase 1 upgrade of the detector, with the aluminization of the top end of the last 600 WLS optical fibers for the TileCal minimum bias trigger scintillators.

In the ATLAS TileCal upgrade, LIP has full responsibility for the new high voltage distribution, to be produced mainly in Portuguese industry. In this new system, sensitive electronics components will be placed in a service cavern and power distribution will be through thin cables to the front end, thus allowing a much greater accessibility for maintenance. In 2019, the team has designed, produced, and started testing the first prototypes of different types of electronics boards required for the system. The supply boards are currently being designed in close collaboration with the LIP electronics laboratory in Lisbon. Within the ATLAS TDAQ, the group is contributing to the Hardware Track Trigger, a new system designed to perform track reconstruction in the trigger. LIP is responsible for most of the production of a communications board with Portuguese industry, and will participate in testing and prototyping other boards. They also take part in the software developments for this system and have already produced the first version of its fast simulation software, in addition to performance studies. In addition, the team is involved in R&D work for the use of hardware accelerators such as GPUs in the trigger system.

Finally, both ATLAS and CMS teams contribute to the LHC Grid computing maintenance and operations.

SELECTED

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J. Brewer, J. G. Milhano, J. Thaler, "Sorting out quenched jets", Phys.Rev.Lett. 122 (2019) no.22, 222301

// CONTACTS

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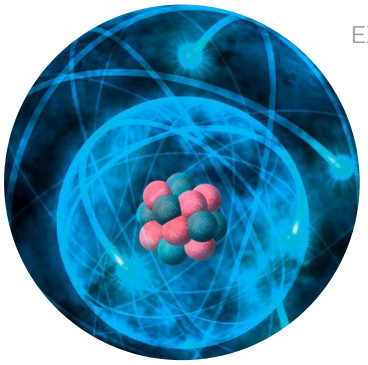
Guilherme Milhano (Pheno), gmilhano@lip.pt



EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

Structure of matter

Looking inside hadronic matter

We still have a lot to discover about the ways in which elementary quarks and gluons work together to form the particles we observe, and that's the focus of LIP's structure of matter research line. LIP's Partons and QCD (PQCD) group is currently involved in the COMPASS experiment, as well as in the preparation of the next steps in CERN's fixed target programme, namely AMBER; FAIR, FAIR-Facility for Antiproton and Ion Research is the new step at GSI and LIP is deeply involved in the HADES and R3B experiments. The NPstrong group has just joined LIP and will bring remarkable theoretical consistency to this research line, as well as opportunities for synergies with other LIP groups.

PARTONS AND QCD – the workings of nucleons

The LIP P&QCD group is heir to a long tradition in CERN's fixed target experimental programme, starting in the 1980s with the heavy ion experiments NA38 and later NA50. The group now concentrates on the COMPASS experiment. Major aims of the experiment are to discover how quarks and gluons contribute to the spin of the proton and to investigate the spectrum of particles that quarks and gluons can form. To do so, they collide high intensity muon or hadron beams with a polarized target at a temperature only 0.1 degree above absolute zero. The experiment uses beams from the SPS accelerator. The target is followed by a two stage spectrometer observing the particles that result from the collision.

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

The LIP group has sole responsibility for the Detector Control System (DCS), an area where it has a recognized unique expertise. The DCS team is responsible for the development and implementation of controls and monitoring for new detectors and systems included in each year's setup. The long shutdown period at CERN during 2019 and 2020 offers the timely opportunity to prepare the DCS for the 2021 data-taking.

Since it joined COMPASS in 2003, the LIP group has been involved in the main analyses of the collaboration, and is a reference in the measurements using the Drell-Yan (DY) process, the production of lepton pairs in hadron collisions. The 2018 COMPASS data-taking was devoted to the study of the pion-induced Drell-Yan process on a transversely polarised proton target. The analysis of the 2015 data, taken in similar conditions, gave first hints of the importance of parton transverse momentum dependent effects to the nucleon dynamics. The 2018 collected sample is now being analysed by the Lisbon team. It will significantly improve the statistical significance of the observed signals. Fast data processing happened in the first months of 2019, and the physics analysis progressed in record time. The first preliminary results were made public by Spring 2019. The unpolarised semi-inclusive DIS data collected by COMPASS in 2016 and 2017 are being analysed at LIP. Charged hadron multiplicity studies, namely on identified kaons and protons, are an important ingredient for fragmentation functions extraction. COMPASS results have evidenced discrepancies with respect to the perturbative QCD theory expectations.

The scientific programme of COMPASS will be completed with the 2021 run. The LIP group is strongly involved in the preparation of a new CERN experiment, AMBER, using the same beam line and parts of the COMPASS spectrometer, to address important QCD-related topics. A Letter of Intent was produced in January 2019, and a Scientific Proposal in May 2019, which started being evaluated by the SPS Committee of CERN in November 2019. The LIP group is one of main proponents, deeply involved in the drafting and discussion with referees. The recent COMPASS results, advances in the theory, and the physics case for AMBER, were among the topics addressed at the XVI International Workshop on Hadron Structure and Spectroscopy, co-organized by the LIP group and the Aveiro/I3N group in COMPASS..

At the frontier between nuclear and particle physics

The accelerator infrastructure at GSI was shutdown during the last five years and is slowly coming back to life. The performed upgrades will put into operation the SIS100 synchrotron at the new FAIR, providing higher beam energies and intensities. LIP is a member of two of the four pillars of FAIR: HADES/CBM and R3B. The first Ag+Ag run at 1.58 GeV took place in March 2019. Both HADES and R3B were among the first experiments to start operation, in the Phase-0 of FAIR.

The upgraded HADES spectrometer, with a new (although incomplete) electromagnetic calorimeter (ECAL) and a new RICH detector, has successfully taken data. HADES is currently the only experiment studying the region of the QCD phase diagram of very high net-baryon densities and low temperatures. Such conditions should allow to produce a state of matter resembling the one resulting from the collision of two neutron stars. Besides the astrophysical relevance, this investigation is a unique contribution to the study of phase transitions in QCD matter, and may shed light on the mechanism responsible for the mass generation in hadrons. Di-electrons originating from in-medium hadron decays are one of the main probes measured in the experiment. The LIP group played a leading role in this area, which culminated in 2019 with a publication in the Nature Physics journal.

The group is in this moment fully committed to hardware activities. The LIP-HADES group was responsible for the design and construction of a Time of Flight (TOF) detector based on Resistive Plate Chambers (RPCs), the RPC-TOF-Wall, and is now responsible for its operation and for the upgrade of the data acquisition system. The group is also designing and constructing the RPC-TOF-FD, the TOF part of the new forward detector that will increase the acceptance of the spectrometer. Changes to the initial design were required, to comply with the demanding rate and multiplicity requirements. A new design was proposed and validated, and the construction of the first modules started in the end of 2019. No production data taking is planned for 2020 in HADES.

The participation in the R3B experiment takes place in the context of LIP's NUC-RIA experimental astrophysics group, developing its activities around fundamental nuclear reaction physics. The group has two main research lines: the study of nucleon knock-out reactions at relativistic energies (in R3B at FAIR) and the study of low energy nuclear reactions with radioactive beams, of interest for nuclear astrophysics (at CERN's ISOLDE facility and related laboratories). During 2019, the group contributed to the preparation and successful execution of the first Phase-0 experiments within the R3B collaboration, under the acronym S444, and participated on site in the first series of measurements. Continuing on the path of studying breakup reactions on halo nuclei, the group is directly involved in two experimental proposals in this first phase. The responsibilities of the LIP group in R3B are focused on the CALIFA calorimeter, for which the group developed instrumentation, simulations and analysis tools. In 2019, the main tasks were testing, performance assessment, and the mounting of the whole CALIFA barrel. An important goal is to participate in the study of halo nuclei using the newly available liquid hydrogen target. Measurement are foreseen for 2021.

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

NPstrong: Let's go also to theory

The Nuclear Physics and Strong Interaction Group is a well established group that recently joined LIP. Currently, the common denominator of the group research activities is theoretical hadron physics. Big motivating questions are the origin of confinement of quarks in hadrons and nuclei, the origin of mass, and the properties of matter in extreme conditions such as heavy-ion collisions and neutron stars. We use non-perturbative functional methods to find QCD solutions for bound systems of quarks and gluons. These methods are complementary to lattice QCD simulations and provide ab-initio solutions for QCD's correlation functions, which subsequently enter in the calculation of hadron observables, where the soft and hard scales are intertwined by non-perturbative integral equations. Applications include hot topics such as the nature of the recently discovered tetra- and pentaquark states. We are also interested in determining the production mechanisms and properties of other exotic hadrons (such as quark-gluon hybrids and glueballs), as well as the spectra and internal structure of "ordinary" mesons and baryons, how they decay and couple to photons. NPstrong naturally connects with several research groups at LIP and will create new synergies. Obvious connections with several groups are established by QCD, namely the ones in this research line, but also the LHC and Pheno groups. NPstrong expertise is special at LIP and ideal for synergistic combination needed to address questions on the dark matter and neutrino sectors.

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EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

Cosmic rays

Messengers from outer space

Planet Earth is constantly being struck by cosmic rays: particles expelled by distant stars and galaxies. These messengers from outer space bring information about the history and composition of the Universe. 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. 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/SWGO project for a future high-energy gamma-ray observatory in the Southern hemisphere.

AMS – a unique particle detector in Space

Since 1998 LIP is part of the international collaboration that designed and operates the Alpha Magnetic Spectrometer (AMS). The project had two phases: a prototype was flown aboard the space shuttle in 1998, and the final detector was installed in the International Space Station (ISS) in May 2011. Since then, a large set of data has been gathered at a continuous rate of around 45 million events/day, corresponding now to about 152 billion events recorded. This detector can identify cosmic ray particles before they interact with Earth's atmosphere. AMS studies cosmic ray fluxes in detail, but also searches for antimatter nuclei and dark matter in the Universe. AMS remains a unique observatory in space and is expected to continue taking data up to at least 2024. LIP had an important role in the design and construction of the Ring Imaging Cherenkov (RICH) detector. Today, the group holds responsibilities on the RICH operations, monitoring and reconstruction algorithms maintenance. The AMS detector monitoring and operation is carried out 24h/24h in the Payload Operations and Control Center at CERN. LIP team members participate performing shifts and acting as on-call experts for the RICH.

Following the AMS launch, the group got involved on data analysis. Solar activity, varying in a periodic way, affects cosmic ray fluxes arriving at Earth, particularly up to rigidity cutoff values around 40 GV. Such variations are expected to depend on the particle charge sign. The LIP group is involved on the measurement of the time-dependent proton flux, to study of the solar modulation of the cosmic rays and interpret it under solar modulation models. Besides the correlation between the sun's activity and the cosmic ray flux, we are interested in the intrinsic propagation mechanisms present in solar modulation, having contributed to the field with several publications already. In 2019 some further work was published interpreting AMS data to study different aspects of cosmic-ray diffusive transport Messengers from outer spacethroughout the solar system, its relation to the solar activity cycle and the temporal variability of the cosmic-ray flux.

Throughout the year 2019 the group got more involved in deuteron/proton separation and flux analysis. Using the Tracker, RICH and ECAL sub-detectors of AMS, and both likelihood estimators and machine learning algorithms in order to separate deuterons from protons, and to estimate the ratio of ^{3}He to ^{4}He in the AMS cosmic ray flux. This work is currently ongoing, and it is fully aligned with AMS' research efforts for the next years. Observations of light isotopes provide information on the origin of cosmic rays and their propagation in the galaxy. Isotope selection and higher charge nuclei identification are topics of extreme relevance for the experiment's future prospects.

Auger – the most energetic particles in the Universe

The Pierre Auger Observatory is the largest Cosmic Ray detector on Earth, covering an area of 3000 km^2 in the Pampa Amarilla, Argentina. It consists of over 1600 detectors separated by 1.5 km that sample the showers of millions of particles produced when the highest energy cosmic rays hit the atmosphere. In dark nights, 27 telescopes detect the ultraviolet light emitted by the showers.The Observatory is taking data since 2004, and has brought new, fundamental insights about the highest-energy cosmic rays. Nevertheless, several open questions remain. The observatory will continue operations until 2025 and is currently being upgraded to become AugerPrime, with the installation of scintillators on top of the each of the existing detectors and the use of faster electronics. This should enable a better understanding of the electromagnetic and muon components of the shower. The muon component plays a big role in unveiling the nature of the highest energy cosmic rays, as

it can probe directly the hadronic component of the shower in its early stages. However, muons are only indirectly accessible even with the upgraded Auger detector. Sophisticated analysis will be necessary to separate them from the dominant electromagnetic signals. For this reason, a small part of the array will be equipped with extra detectors to understand and calibrate, at a lower energy, the measurements of the full array.

The LIP team has two broad lines of work: the detailed study and development of detectors to improve data quality; and data analysis, fully exploring the data to get insight into the physics of shower development and hadronic interactions at high energies.

Concerning hardware, in the last few years the LIP team has been leading MARTA, a joint Portugal-Brazil project to measure directly the muon content at the shower using RPC detectors installed beneath the current Auger detectors. Low gas flux RPCs developed at LIP-Coimbra were built in cooperation with Brazilian institutes. Prototypes have been working on a regular basis at the Observatory site. MARTA detectors will be used for a deeper understanding and a more precise calibration of the Auger surface detectors, to validate and test in situ the scintillation detectors and for detailed shower studies at lower energies. In 2019, the first MARTA station was installed in the field, and the construction and deployment of the support structures for the remaining stations is close to completion. A required upgrade in the slow control subsystem and the installation of further stations will continue in the next visit to Argentina, in early 2020.

As for data analysis, the observation of more muons than expected from current models is one of the most intriguing questions raised by Auger data. Furthermore, the detailed study of both the electromagnetic and muonic shower components is crucial for the determination of the nature of the primary particle and to disentangle it from the modeling of hadron interactions. The LIP group is directly involved in this quest, exploiting hadron interactions at high energies through a window that is largely complementary to the LHC. The team has acquired a deep knowledge in shower physics and developed innovative tools that will allow us to give important contributions in the analysis of the new Auger data. In 2019, the detailed studies of the shower development have been pursued focusing in understanding the driving parameters of the shower development. Several important results have been produced, including the measurement of the muon content fluctuations and the probing of the energy spectrum of neutral pions in the first interactions of the showers. The team had a strong impact on the cosmic ray community presenting these results at the International Cosmic Ray Conference, and led a multi-experiment working group, which has reported an increase of the muon excess in data with respect to simulations with the primary energy.

At the top of the mountains

Present and planned large field-of-view (FoV) gamma-ray observatories are installed in the Northern Hemisphere, missing, in particular, the galactic centre, and have energy thresholds above 0.5 TeV. The LIP-LATTES group, together with INFN-Padova (Italy), CBPF (Brazil) and MPKI (Germany) groups, worked together to establish a joint project to design a ground array observatory able to monitor the Southern gamma-ray from 100 GeV up to 100 TeV. As a result the Southern Wide-Field Gamma-ray Observatory (SWGO) collaboration was launched in July 2019, and gathers already more than 100 scientists from 10 countries.

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

LIP has a leading role driving the efforts to access to the so-called sub-TeV gamma-rays, which would cover the energy gap in sensitivity between satellite bourne and ground-based measurements. The work done in 2019 included exploring the physics potential (in particular for transient phenomena such as GRB and AGN flares), improving the observatory concept, and performing R&D both in analysis methods (namely using advanced Machine Learning techniques to improve the separation of gamma and hadron initiated showers) and on detectors (namely studying detector performance optimisation at extreme altitudes (of the order of 5000 meters).

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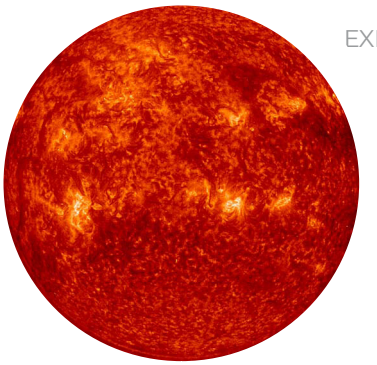

EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

Dark matter and neutrinos

Hunting for the most elusive particles

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

Searching for the dark side

LUX-ZEPLIN (LZ)

According to the most recent experimental evidence, dark matter makes up 27% of the total density of the Universe. We have strong clues that dark matter is made of particles that interact very weakly. One of the ways to search for it is to use super-sensitive underground detectors to identify very rare interactions between dark matter particles that cross the Earth and normal matter particles. The LIP Dark Matter group joined the LUX experiment in 2010 and is a founding member of the LUX-ZEPLIN (LZ) international collaboration in 2012. Both search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs), aiming at their direct detection with two-phase xenon Time Projection Chambers (TPCs).

LUX (Large Underground Xenon) was an experiment based on a 250 kg xenon TPC that published three world leading limits on the spin-independent cross section for WIMP-nucleon scattering in the 5-1000 GeV mass range. LUX was decommissioned in the Autumn 2017. The analysis of its data is still going on and producing a rich set of publications, covering a large variety of topics from the search for axions and sub-GeV dark matter particles to Xe isotopes rare decays or innovative calibration techniques, several aspects of the physics of xenon as detector medium and the detector performance. In 2019, the LIP team completed the LUX data analysis regarding the search for the double capture of ^{124}Xe and ^{126}Xe.

LUX-ZEPLIN (LZ) is a second-generation dark matter direct detection experiment. It moved underground, to the 4850-feet level of the Sanford Underground Research Facility (SURF) in October 2019. The complete assemblage and integration will last until middle Spring 2020. The first liquid xenon filling of the detector is expected to take place in the beginning of Summer 2020 followed by the TPC commissioning and performance tuning. The first science run is expected to start by the end of 2020 and will last for 6 months (170 live days). It will be followed by three months for calibrations and maintenance. The second science run will last for about 450 days. The third run is expected to extend from beginning 2023 to mid 2025. In parallel with the detector deployment, an intense activity of simulation, R&D of data analysis tools, their implementation and validation is taking place.

The LZ detector uses a 7 tonne active mass of purified xenon in a dual phase TPC to search for potential signals from WIMPs. With 5.6 tonnes fiducial mass and 1000 live-days long dark matter search, the projected spin-independent cross section sensitivity is 1.4 x 10^{-48} cm^2 for a 40 GeV WIMP mass, roughly 50 times better than the current best limit.

In 2019, the dark matter LIP group has made crucial progress in the responsibilities assumed in LZ, namely the control system, the data quality monitor, data analysis tools at the level of pulse characterization and vertex reconstruction, background accounting and modeling. We were also the main group studying the sensitivity of the LZ detector to the neutrinoless double beta decay (0v2ß) of Xe^{-136}, the second most important physics goal of LZ. The observation of this process would show that neutrinos are their own anti-particle (Majorana particles). We have also studied the sensitivity of LZ to the double beta decay (with and without neutrino emission) of ^{134}Xe.

Searching for the elusive neutrinos

SNO+

The LIP Neutrino physics group joined the SNO experiment in 2005, and is a founding member of the SNO+ international collaboration. The Sudbury Neutrino Observatory (SNO) measured the oscillations of solar neutrinos, i.e., their

transformations from one type to another (Nobel prize in Physics 2015). The detector is located 2 km deep underground, in SNOLAB, Canada. An acrylic sphere with 12 m diameter and 6 cm thickness, that contained 1000 tons of heavy water, is surrounded by 9500 light sensors. SNO's analysis on the search for the hep solar neutrino flux is now completed and ready for publication, with the participation of the LIP team. These are the rarest and most energetic neutrinos emitted by the Sun. The SNO+ experiment follows from SNO. The main goal of the experiment is the search for neutrino-less double-beta decay, by loading the scintillator with large quantities of Tellurium. The observation of this process would be a breakthrough in the understanding of the nature of neutrinos, revealing that they are Majorana particles. Several other low-energy, low-background, physics topics are also part of its program: antineutrinos from nuclear reactors and the Earth's natural radioactivity, solar and supernova neutrinos, and searches for new physics.

After taking data with the detector filled with water in 2018, the SNO+ started the scintillator fill in 2019. Our team maintains its responsibilities in calibrations and support analyses, such as background estimation, while gradually shifting focus towards physics analyses. The second calibration source deployment device, built at LIP-Coimbra, arrived at SNOLAB, while the first has been sent underground. The LIP-Lisboa control room was successfully used to carry out most of our shifts remotely. During 2019, the team was very active in the analysis of the data from water and partial scintillator fill phases. The water phase neutron calibration data analysis resulted in the measurement of the neutron proton capture cross-section with high sensitivity, to be published soon. We are testing the water phase antineutrino analyses, including a better evaluation of backgrounds. Concerning the scintillator phase preparation, the LIP team coordinate the analyses of the scintillator optical and radiopurity properties with SNO+ data, providing weekly feedback to scintillator purification and filling operations. The scintillator fill is expected to be completed in 2020. We expect to collect SNO+ data with partial scintillator fill during 2020, pure unloaded scintillator following that, and Te-loaded scintillator from 2021 onwards.

DUNE

The discoveries of the last few decades have brought neutrinos to the fore in seeking answers to fundamental questions about the composition and evolution of the Universe. DUNE will certainly be one of the great projects of the next decades in the search of these answers, studying in particular the mass hierarchy of neutrinos and CP violation. DUNE is a long baseline experiment, for which neutrino and anti-neutrino beams will be produced at Fermilab and detected 1300 km away at SURF, in large Liquid Argon (LAr) TPCs. The beam is expected in 2026, and the first detector installation in 2025. A prototype of a single phase LAr TPC (ProtoDUNE) took beam test data and is now collecting cosmic rays at CERN; a double phase (liquid + gas) was commissioned and started taking cosmic ray data in 2019.

LIP joined DUNE in 2018. The activities have quickly ramped up in 2019, with a clear focus on the design of the far detector (FD) calibration systems and on operations, commissioning and analysis of the ProtoDUNE prototypes at CERN. We focused on the baseline calibration systems for the FD and their interface to the DAQ system. We contributed as co-editors and coauthors of the calibration chapters of the Technical Design Report, now submitted for publication. The Cryogenic Instrumentation and Slow Controls Consortium is lead by the LIP team. We have performed maintenance and operation of the trigger system for ProtoDUNE-SP, being responsible for the design of new trigger configurations, maintenance of the firmware and software, and support to the data analysis groups. We have participated in the installation and commissioning of the ProtoDUNE-DP detector at CERN, and on the readout of the slow control data from all the cryogenic instrumentation sensors.

SHiP

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

The LIP SHiP group has been created in 2018, and is involved in both detector R&D and analysis. Currently our group is responsible for a 2x10 m^2 Veto Detector, based on RPC technology, whose purpose is to veto events originating in neutrino or muon DIS. In addition, the group is also competing for the construction of a 50 m^2 Timing Detector with the aim of suppressing the muon combinatorial background. Both detectors are crucial to ensure a nearly zero background environment for the experiment. The group is involved in the optimization of the selection of several Hidden Particles (HP). Machine learning algorithms are being developed at LIP to ensure the desired background level and to obtain automatic event probabilities for different HP. The group intends to start a collaboration in tau neutrino analyses with the SHiP neutrino group.

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Development of new instruments and methods

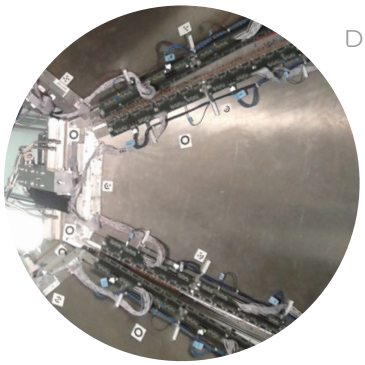
- Detectors for particle and nuclear physics
- Health and biomedical applications
- Space applications

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

The development of new instruments and methods related to experimental particle physics has been from its inception one of the main pillars of activity at LIP. Over the years, LIP has built a high level of expertise in key radiation detection technologies, supported by research on the fundamental processes involved.

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

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



DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

Detectors for particle and nuclear physics

Technology to see the invisible

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

RPC R&D: pushing the limits of performance and versatility

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

RPC-PET: medical imaging

An important line of work is the development of RCP-based devices for medical imaging through Positron Emission Tomography (PET). For more details on this, please turn the page and have a look at the Health and Biomedical Applications research line (page 42).

Time and Position sensitive RPCs

RPCs providing high time precision (tRPCs), and thus accurate measurements of the time-of-flight (TOF) of particles, continue to be one of the main technologies for the identification of particles in high energy physics experiments, whenever large detection areas are needed. The group is developing this technology based on an innovative concept for the construction of RPCs, achieving a 98% efficiency together with 50 ps time precision in large area detectors of around 2 square meters. Such detectors are developed to be used in particle physics experiments in which LIP participates, namely HADES and SHiP, The precise measurement of position (PS-RPCs) in combination with time (PS-tRPCS) is of especial interest for particle identification but also find direct application for example in muon tomography. Both transmission tomography (e.g. volcano and mine imaging) and scatter tomography (container scanning) are of interest to the group. As an example, a 4-layer RPC device , a prototype for muon tomography of cargo containers at harbors, for the HIDRONAV S.A. company, has been constructed, integrated and deployed. Continuing with the collaboration with HIDRONAV company, a project for the construction of two cosmic ray telescopes for the monitoring of the stratosphere temperature is now under development/ construction implementing the lessons learned in the first device. The system is a pre-prototype for a future macro-scanner for cargo container scans. In addition, during 2019 the MUTOM telescope (a four plane RPC telescope equipped with low power consumption electronics capable of operating with solar panels) has been designed and built in LIP infrastructures. After integration, it will be installed in the Lousal mine for a muon tomography exploratory project, a joint activity with the LIP cosmic-rays groups Auger and LATTES.

Finally, the group is deeply involved in TRISTAN, an autonomous cosmic ray telescope for the precise measurement of the cosmic ray flux. The telescope, designed and built at LIP, performed two latitudinal cosmic-ray survey from Iberian peninsula to Antarctica, where it is now permanently installed and operational (during the summer months) at Spanish Juan Carlos I base. This has provided an invaluable experience in detector remote operation. The analysis of the data from the first latitudinal survey, showing a precise and stable (< 1%) measurement of the cosmic ray flux, is being performed and the preliminary results were presented at the beginning of 2020 at the RPC2020 workshop.

Autonomous RPCs

The development of RPCs, able to operate outdoors, reliable, performant, and solar panel powered, is an extremely interesting technology for cosmic ray experiments. This line of work has been pushing RPCs to different limits of extreme

conditions. After a few years of R&D, construction and testing, the production of the MARTA RPC detectors for the Pierre Auger Observatory, able to work with very little maintenance and a very low gas flux, was completed in 2019 in collaboration with our Brazilian colleagues. They are now being installed at the Observatory site, mainly for calibration, systematic studies, and future detector R&D purposes. A more recent challenge is the development of the RPC chambers for the LATTES project, also with low gas flux and very little maintenance, but able to operate at altitudes of the order of 5000 meters. For this, a small hypobaric chamber and further instrumentation has been prepared in 2019, and development and testing will start soon. Finally, sealed RPCs (no gas flux) would be a breakthrough in the field. During 2019 several prototypes of sealed chambers were made and at this moment a final design with promising results is being tested. The recently approved project RPCADVANCE will be fundamental to advance in this matter and to push forward the fundamental R&D in RPCs, necessary for the improvement of the detectors and to be able to expand their possibilities.

RPCs for the neutron detectors of the (near) future

Neutron detectors are a critical component of neutron scattering instruments, finding application in a wide range of disciplines including material, chemistry, biology, life and heritage sciences, homeland security and industry. The drastic shortage of ^{3}He during the last decade and the ongoing construction of new high intensity spallation neutron sources, most importantly the European Spallation Source (ESS), strongly motivated the development of alternative neutron detection technologies to replace the one based on ^{3}He. Currently the emphasis is on the development of detectors with high rate capability, high spatial resolution and fast timing, which are able to meet the requirements of a new generation of instruments, such as, e.g., reflectometers and diffractometers to be installed at ESS. The LIP group has introduced and is developing a pioneering concept of a position sensitive thermal neutron detector (PSND) based on RPCs lined with $^{10}B_4C$ solid neutron converters. This technology offers very high spatial and time resolution in comparison with competitive technologies. Also, the practical advantages of detectors of this type are manifold: high modularity of the design, robustness, good scalability and low cost per unit area. The group has already demonstrated that this technology is capable to provide high (>60%) detection efficiencies for thermal neutrons and is very well suited for neutron imaging: a prototype of ^{10}B-RPCs PSND with 2D position readout, tested at neutron beam, has shown a spatial resolution of 0.25 mm, which is unprecedented for large area detectors. However, there were two important challenges that had to be addressed: to boost the counting rate by a factor of 100; and to demonstrate that the sensitivity to gamma ray background can be less than 10^{-5}. The work performed this year has resulted in several important breakthroughs. Several new detector prototypes featuring low resistive materials for RPC electrodes were tested at the HZB neutron source in Berlin. The results show an order of magnitude increase in the maximum counting rate compared to the previous generation of single-layer RPC detector. Combined with an order of magnitude improvement in the rate expected from simulations for a multilayer detector, these results show that the current limit on the counting rate density can be improved by two orders of magnitude, reaching in perspective 100 kHz/cm, which is one of the most important milestones on the way to broad implementation of these detectors. On the other hand, an experimental study has demonstrated that this type of detector can be operated with gamma sensitivity below 10^{-5} for 0.511 MeV photons, satisfying an important requirement for detector applications at high background conditions. Finally, while we have already demonstrated a spatial resolution of 0.25 mm, there is a potential to approach 0.1 mm resolution, opening new possibilities for neutron science instrumentation.

R&D on gaseous and liquid Xenon detectors

Another speciality of LIP are detectors based on the use of xenon as the active material. The high density and high interaction cross sections with ionizing radiation make Xe an ideal detection medium for many applications. Although the energy ranges of interest may vary, from the detection point of view they have very much in common. Currently, these lines of work are mostly carried out in the context of the RD51 collaboration at CERN.

Ion mobility measurements

The group has an unique expertise in performance studies of gas detectors in the challenging range of low energy (few hundred keV), and more recently also in the higher energy range (few MeV). Its main investigation areas are the study of the drift parameters of charged particles, both electrons and ions (positive and negative), in noble gases and their mixtures used as detector's fillings, with the aim of finding the more suitable medium for each application. Monte Carlo simulations are used, together with detector prototypes and experimental systems adequate for the measurement of the relevant quantities. The knowledge acquired by the group in the last years allowed to establish international collaborations, namely with the NEXT collaboration that uses a high pressure electroluminescent Xe TPC to search neutrinoless double beta decay and with the RD51 collaboration.

Liquid Xenon detectors

The team is also focused on the processes triggered by particle interaction with liquid xenon and associated technologies, focusing on giving significant contributions to the future generation of liquid xenon detectors. The scope of activities encompasses all the electronic, optical and molecular processes generated in a single- or double-phase liquid xenon detector due to particle interactions in the medium. These activities are developed in the framework of CERN's detector R&D collaboration RD51. Our focus for the next few years will be studying satellite signals in liquid xenon double phase electroluminescence TPCs. In 2019, the necessary bench-top setup for studying secondary effects in xenon electroluminescencce TPCs (gas and liquid) was acomplished. In addition, studies and test of different techniques of electronic excitation of xenon together with the construction of materials suitable for the ultraviolet wavelength region have been done.

Scintillating Detectors and Optical Fibres

LIP has expertise in detectors based on radiation-hard scintillators and scintillating or wavelength-shifting optical fibres. We decisively contributed to the ATLAS TileCal calorimeter and to a number of other projects. LIP has experimental labs in Lisbon (LOMaC), dedicated to instrumentation for processing and characterization of optical wavelength shifting and scintillating fibres, plastic scintillators and photomultipliers. See LOMaC on page 52 for further details.

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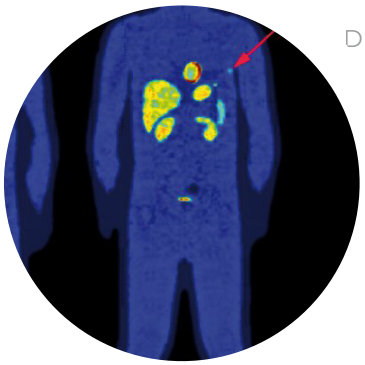

DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

Health and biomedical applications

Interdisciplinary projects for healthcare instrumentation

LIP's expertise in planning, building and operating detectors for particle physics finds natural application in radiation and particle therapy instrumentation, dosimetry and medical imaging. These areas are covered in multidisciplinary projects developed in collaboration with partners such as the ICNAS institute for nuclear health applications, the CTN/IST centre for nuclear technology, and several hospitals and medical research centres. It has recently been confirmed that a centre for proton therapy will be installed in Portugal. LIP is a founding member of the ProtoTera Association, created in 2019 to promote the development of a national research network in advanced therapies and associated technologies to treat cancer patients. This makes a perfect fit with LIP's health and biomedical application activities, and is certainly an excellent opportunity for establishing interdisciplinary partnerships in a field with important social benefits.

Medical imaging with RPC-PET

Positron emission tomography (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 neighbouring molecules, they annihilate, producing two very energetic photons traveling in opposite directions. These photons are identified by the surrounding detectors, to create detailed images of the organism and to monitor dynamic processes. This line of work has been pursued by the RPC experts at LIP for a number of years. The RPC-PET technology has been applied successfully in pre-clinical PET. A high-resolution, small animal RPC-PET scanner developed at LIP is installed at ICNAS since 2014. Hundreds of tests have been performed on mice, with goals such as studying the molecular mechanisms underlying degenerative diseases or testing new drugs that may be used to treat certain diseases. This technology has the potential to be applied in human brain PET. The project "HiRezBrainPET: neurofunctional cerebral imaging by high resolution positron emission tomography", led by the company ICNAS-Produção Unipessoal and with a strong participation from LIP was approved in mid 2019. We will develop an innovative PET scanner with sub-millimeter spatial resolution using RPCs. This equipment has the potential to change the paradigm in the diagnosis and investigation of diseases of the central nervous system by allowing, for example, to see small brain structures such as the striatum, amygdala and thalamus subnuclei, involved in neuropsychiatric diseases. On the other hand, the high spatial resolution of the system may play an important role in the characterization of vascular injury, improving the diagnosis and guiding the therapy, and in the detection and staging of central nervous system tumors, allowing a better planning of surgery and radiotherapy. The conceptual design has already been developed, covering the main system components and fundamental alternatives. A preliminary study using existing hardware allowed to test the main system components: trigger. position electronics, readout electrodes, detectors, electrical shielding, etc. The first HiRezBrainPET detector head will now be produced at LIP and tested, incorporating the lessons derived in the design. We hope to produce the final four heads by the end of the year.

Proton-therapy Instrumentation

ProtoTera, the Portuguese Proton-Therapy and Advanced Technologies for Cancer Prevention and Treatment Association, will promote the development of a national research and education network on advanced therapies and associated technologies, leveraging the research, training and healthcare infrastructures associated with the treatment of patients with cancer using new technologies. Areas and technologies covered include, among others, high-energy particle beam therapies, theranostics for the enhancement of precision, personalised medicine, and advanced medical imaging. Founding members are the Portuguese Institute of Oncology Hospital Group, Instituto Superior Técnico, the University of Coimbra, and LIP. ProtoTera will also promote fundraising and networking among the various associates and other entities, and ensure international scientific, technical and clinical cooperation, in particular with the International Atomic Energy Agency and international reference centers, namely CERN, GSI, Heidelberg University Hospital, MD Anderson Cancer and Trento Proton Therapy Center. Within this interdisciplinary network, several groups at LIP have the potential to give major contributions.

Real-time beam monitoring and imagiology

Orthogonal Ray imaging (OR imaging) is one of LIP's core projects for radiation and particle therapy instrumentation, and is developed in partnership with two Portuguese oncology institutes, the Hospital of the University of Coimbra and several medical research centers. The aim is to improve radiotherapy by optimizing the treatment in near real time, so that the irradiation can better accommodate the tumor and spare surrounding healthy tissue. To do this, we make use of x- or gamma-rays emitted orthogonally to the treatment beam. The OR Imaging technique may be divided into two main branches: OrthoCT (orthogonal computer tomography) for monitoring radiotherapy (high-energy x-rays); and O-PGI (orthogonal prompt-gamma imaging) for monitoring proton therapy. In the last few years, both experimental work and ever more realistic simulations have been performed. The rotation-free, low-dose imaging capability of both OrthoCT and O-PGI are two of its great strengths. The imaging capability of OrthoCT has recently been experimentally demonstrated. The on-board (just prior to the therapy session) or real-time imaging making use of the therapeutic beam (consequently without extra dose to the patient), is another potential strength. The goal is to demonstrate beyond doubt to the medical community the usefulness of both OrthoCT and O-PGI in megavolt X-ray radiotherapy and proton beam therapy in a variety of cases: head-and-neck, pelvis (bone tumor and prostate), lung, total-body irradiation in pediatric tumors, among others.

The OR-imaging group is part of two recently approved projects which will have an important impact in the future activities. The project "TOF-PET for Proton Therapy (TPPT)", in the framework of the Portugal-Austin collaborative projects, is led by the LIP's spin-off company PETsys Electronics and involves several institutions in Portugal and in Texas, EUA. The aim of the project is to demonstrate the feasibility of PET with very good time of flight resolution for range verification in proton therapy. The range verification will be based on the observation of positrons from the decay of ^{15}O during and immediately after irradiation, using in-beam PET. Proton range verification will be based on radionuclide production rate maps. A computer simulation will predict the distribution of the positron annihilation events that should be observed. Any mismatch will indicate a range error and will allow correction by changing the beam energy. The project "Proton therapy: real-time prompt gamma imaging and micro-dosimetry (PrototerapiaPT+)", to be developed in collaboration with the LIP Dosimetry group, intends to further develop competences in instrumentation for radiation detection and measurement existing at LIP, to support a future proton-therapy facility.

Dosimetry

The LIP dosimetry group has a long experience in the design and construction of detectors for medical applications. It pursues two lines of work: clinical dosimetry, focused on the application of plastic scintillators and optical fibers in the context of clinical dosimetry for particle therapy; and high-resolution dosimetry and microdosimetry, focused on studies of radiation effects at the cellular level aiming at determining the biological efficiency and induced damage of high-LET (linear energy transfer) radiation. In the last year, the preliminary studies for a project on high-resolution dosimetry that intends to develop a prototype for radiobiology studies based on very thin scintillating optical fibers were performed. For this, we started to test the response of scintillating fibers to proton beams. This will have the unique capability to support the growth of the biological system to be irradiated. We will develop a real-time dosimetry array consisting of tissue-equivalent material in conjunction with a novel 3D human skin model, as this is one of the dose-limiting organs in proton-therapy. This project (3d-DoSkin) will be developed in collaboration with LIP's LOMaC and with biology groups from BioISI/FCUL and ITQB-NOVA. A proposal was recently submitted to the UT Austin-Portugal program for exploratory projects, involving the M.D. Andersen Cancer Center. We also continue to develop our competences in the application of Monte Carlo simulations, namely, Geant4-DNA to study physicochemical effects at cellular level. In the context of a joint work of the LIP Dosimetry and SpaceRad groups, another exploratory project was proposed to the UT Austin-Portugal program, also collaboration with the M.D. Andersen Cancer Center, regarding FLASH (proton beams at very high dose rate) therapy.

Other tools and expertise

At LIP, there is an accumulated expertise on position-sensitive scintillation detectors (PSSD), developed in contexts as different as medical imaging with gamma cameras, dark matter searches or neutron detectors. The resulting auto-calibration and fast calibration algorithms for PSSD, as well as the corresponding PSSD simulation, data processing and reconstruction software toolkit (ANTS2), are widely used by most detector development and applications groups at LIP, and also outside LIP.

ANTS2 is highly configurable and easy to adapt to new situations and is also interfaced to GEANT4. The self-calibration technique can be applied in a number of different situations. For example, in 2019 a neutron Anger camera has been assembled in collaboration with LIP's Neutron Detector group. Using ANTS2, the camera design has been optimized, a statistical method was used for event reconstruction and the adaptive response reconstruction procedure was implemented, which gives the detector unique self-calibration capabilities. The results were published together with the detector group from ILL (France).

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DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

Space applications

Into outer space

Space exploration is a natural area of application of particle physics technologies, especially in what concerns radiation detection instrumentation and the modeling of complex processes involving the interaction of radiation with matter. The radiation environment in space is the combination of several sources: in addition to the solar wind, particles emitted continuously by the sun and cosmic radiation coming from outside the solar system, the sun emits sporadic and intensely electrons, protons and ions with energies up to 1 GeV. Additionally, planets with magnetosphere are surrounded by belts of trapped charged particles.The radiation environment affects spacecraft instrumentation and is one of the greatest constraints for future manned missions. The detailed knowledge of the radiation environment is essential to establish radiation hazards mitigation strategies in space mission planning and operation.
Over the last decades, LIP became a recognized partner in the space community. LIP is today a partner of the European Space Agency (ESA) in several planetary missions and consortia for the development of scientific instruments. The recent creation of the new Portuguese Space Agency is expected to boost the activity in Portugal, both in academia and in industry.

Space Rad: Radiation environments and more

For the last 16 years the activities of the SpaceRad group at LIP have been addressing the various problems and questions posed by ionizing radiation in Space. The competences developed by the group include all the areas and technologies identified on ESA's roadmap for this domain, and LIP is the academic reference in these areas: radiation environment analysis and modeling; radiation effects analysis tools; radiation measurement technologies; radiation hardness assurance of Electrical, Electronic and Electromechanical components (EEE). In its activities, mostly developed under contracts with ESA, LIP works with different entities, both from academia and industry.

During 2019, in the field of radiation measurement technologies, LIP has been participating in the consortium that is developing RADEM the radiation monitor for ESA L-class mission to the Jovian system, the JUICE mission, to be launched in 2022. RADEM is not only a radiation monitor, but a spectrometer that will allow to measure the energies of protons and electrons, as well as to discriminate the directions of the incident electrons in the complex magnetosphere of Jupiter. LIP is responsible for the full radiation analysis of RADEM, the Total Ionising Dose (TID) testing of the RADEM custom made ASICs and for the development, calibration and performance study of RADEM´s directionality detector.

Since 2011 and up to 2019 LIP participated in several contracts, both for the preparation, and for the analysis of AEEF data – the Alphasat Environment and Effects Facility) platform is a Technology Demonstration Payload aboard the ESA Alphasat satellite, in geostationary orbit since 2013, which includes a radiation monitor, the MFS, and a test bed for electronic components in flight, the CTTB.

The SpaceRAD group was responsible for the ground calibration of the CTTB RADFET dosimeters, and for their use in-flight dose calculation and for the analysis of the behaviour of CTTB electronic components. Additionally, detector simulations were used to compute the response function of the MFS, enabling to develop algorithms for the calculation of proton and electron spectra measured in Geostationary Orbit. The analysis of the AEEF data has enabled to engage Master Students, providing advanced training in the field of space applications, while collaborating with international partners in the analysis and interpretation of in-flight Particle Spectra data.

Since 2008, the SpaceRAD group is responsible for the development of a model of the radiation environment on Mars based on Geant4, the detailed Mars energetic Radiation (dMEREM). Since its release this model has been constantly improved and updated to comply with the latest versions of Geant4. In 2019 we worked in the validation of the dMEREM model with data from the Martian surface, measured with the RAD detector – RAD is among the instrument suite of the Curiosity rover and it is the only energetic particle radiation detector ever deployed on the Martian surface, which occurred in 2012. The group is currently working on its use in assessing radiation hazards in future manned missions to Mars and for astrobiology studies.

Since its inception, the SpaceRAD Group relies on a very strong expertise in Geant4. As such, during 2017 and 2018 a tool and user interface enabling to directly export CAD STEP format geometries, with corresponding materials, into a GDML format, which can be directly read by Geant4, was developed. This tool, GUIMesh, provides an easy to use and fast methodology to introduce complex geometries in Geant4. During 2019 it was applied to the ongoing projects, such as RADEM, the CTTB and the MFS data analysis, and it will continue be a very valuable asset for future work.

i-Astro: astrophysics instrumentation in Space

The i-Astro group holds high-level competences in instrumentation for astrophysics, particularly in x- and gamma-ray polarimetry. It develops its research activities in the framework of mission proposals to ESA and NASA in the x- and gamma-ray domains. The group is part of the H2020 AHEAD (Activities in the High Energy Astrophysics Domain) project, as well as of the AMEGO (All-sky Medium Energy Gamma-ray Observatory) and IXPE (Imaging X-ray Polarimetry Explorer) space missions consortia. Our group is contributing to the development of detection plane instruments based in CdTe, CZT, CsI, Si and in gas filled detectors, with polarimetric capabilities. Polarimetry in high-energy astrophysics has known very few developments, however it has a great potential to open a new scientific observational window. AHEAD2020 was selected for funding for 4 years more, starting in March 2020.

In 2019, in the framework of AHEAD WP9 (Work Package 9), entitled "Gamma-ray experiments", e-ASTROGAM and AMEGO instrument mass models were simulated and its polarimetric performances were assessed.

Polarimetric measurements with a double layer CdTe prototype under a polarized beam at the ESRF (European Synchrotron Radiation Facility) and at LARIX (LARge Italian X-ray facility) facility at the University of Ferrara were performed. Progressing to the new AHEAD2020 EU funded project our group will take part in WP11 "Space Experiments for HE Astrophysics & Multi-messenger Astronomy" activities developing a compact Compton Telescope (COMCUBE) prototype, Cubesat-compatible, that offers game-changing GRB polarimetric capability in the few hundred keV range.

Research activities under the project ProtonRadCdTe (Protons Radiation Hardness in CdTe Detectors for Space Instrumentation) were carried out. The project aims to characterize the effects of orbit proton radiation environment on CdTe based instrument in the context of a Low-Earth Orbit (LEO) mission: i) the damage effects on the CdTe crystals and the deterioration of the detectors operational performance, ii) the nuclear activation in CdTe material and the gamma-ray background noise. We contributed to analyze of the proton radiation sensitivity of CdTe detectors, using a low MeV range proton radiation field, generated in a cyclotron facility. The present study is important in the framework of the development of a CdTe instrument for a medium energy gamma-ray observatory, anticipating the possibility of future short to long-duration LEO mission, up to ~20 years. We kept contributing to the development of the main instrument of NASA IXPE mission, by simulating the potential polarimetric performances of different noble gases: Xe, Ar, Ne and He.

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Computing

- Scientific computing

Scientific research requires increasingly higher data storage and processing capacities that stress the limits of information systems and related technologies.

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

Scientific computing is certainly one of the areas placing LIP at the forefront of innovation.

The LIP computing groups have extensive knowledge and experience in scientific computing, excellent international relations and integration in scientific e-infrastructures, with users from multiple disciplines and organizations, participates in the FCT infrastructures, and in the enabling of future policies for scientific computing and open access.

LIP co-leads the National Infrastructure for Distributed Computing, serving the Portuguese scientific community at large, and has growing expertise in data science and big data.

Furthermore, LIP has a wide knowledge on advanced big data analysis techniques, which will be very much reinforced by the arrival of the new SPAC group. To exploit knowledge transfer opportunities and to address societal changes in this area is certainly a priority.

Computing

Enabling Compute Intensive and Data Intensive Science

The LIP distributed computing and digital infrastructure activities encompass the support for scientific research, through the provisioning of computing services, complemented by a component of innovation aimed at staying at the forefront of computing technologies, namely through a strong participation in some of the main European R&D projects in the field.

Distributed computing and digital infrastructures

The LIP distributed computing and digital infrastructures group provides information and communications technology (ICT) services to LIP. These services support research, innovation, management, advanced training and outreach activities. The group has extensive experience in delivering compute and data oriented services for simulation, data processing and analysis. The services portfolio includes the Portuguese Tier-2 computing facility integrated in the CERN Worldwide LHC Computing Grid (WLCG). WLCG is a global collaboration of more than 170 computing centres in 42 countries, linking up national and international e-infrastructures. The development of the group competences and capabilities is backed by the participation in R&D&I projects at national and international level. The group participates in European projects related to the development and exploitation of digital technologies applied to both compute and data intensive science. The current activities are focused on distributed data processing using cloud computing, high throughput computing, high performance computing and machine learning. The group is participating in the H2020 projects: EOSC-hub, DEEP-Hybrid-DataCloud, and EOSC-Synergy. Based of the the accumulated experience the group is also delivering scientific computing services to the wider Portuguese scientific and academic communities in the context of the Portuguese National Distributed Computing Infrastructure (INCD), of which LIP is the main technological partner. The group is also engaged in national activities related to High Performance Computing (HPC) in the context of the national advanced computing network. The group activities bridge at international level with science related infrastructures and initiatives such as the European Grid Infrastructure (EGI), Iberian Grid Infrastructure (IBERGRID) and European Open Science Cloud (EOSC). In this context the group collaborates with several research communities beyond High Energy Physics.

The LIP group coordinated the INCD technical activities including development and operations. The deployment of the equipment purchased by INCD for the Lisbon center was completed by the LIP team. The equipment funded by the FCT infrastructures roadmap will be used to support the national academic and research community within the FCT advanced computing network, of which INCD is one of the infrastructure providers. In this context the cloud, HPC and HTC services were improved and the software upgraded or redeployed. The INCD network backbone in Lisbon was also fully upgraded. A new INCD operations center has been established at LIP Minho with INCD staff integrated in the LIP computing group. Through this center, LIP participated together with FCT-FCCN, INCD, and MACC (Minho Advanced Computing Centre) in the deployment of the BOB supercomputer at Minho. This is the largest High Performance Computing facility in the country and is split in two computing partitions currently operated by MACC and INCD. The storage system that serves both partitions was deployed and is managed by the LIP team in Lisbon, while the computing partition allocated to INCD is being managed by the INCD team in LIP Minho. INCD also deployed additional equipment to reinforce the Minho facility.

The Tier-2 and LIP computing farm services established on top of INCD have been improved. In 2019 the Portuguese Tier-2 in the World Wide LHC Computing Grid (WLCG) delivered more than 110,000,000 normalized (HEPSPEC06) processing hours to ATLAS and CMS. The increase of delivered capacity was possible thanks to the new INCD equipment in Lisbon.

The group participated in the EGI governance and technical activities liaising Portugal with this international infrastructure. The IBERGRID collaboration continued providing an umbrella for a common Iberian participation in EGI and EOSC. The EGI middleware coordination was again performed by LIP, IFCA and CESGA in the context of the IBERGRID collaboration. The 10th IBERGRID conference was held in Santiago de Compostela, it was organized by CESGA, IFCA and LIP and counted with more than 100 participants.

The LIP group participated in the FCT advanced computing work group, in several activities towards the national participation in EuroHPC, namely the European proposal for national competence centers in EuroHPC. Within the context of the Eu-

ropean Commission Open Science Cloud (EOSC), LIP continued the participation in the EOSC-hub project that joins EGI, EUDAT and the INDIGO-DC consortium. Within this project LIP is coordinating the software management activity for all infrastructures federated in EOSC-hub at European level. Also in EOSC-hub, LIP continued to collaborate with LNEC to develop and operate OPENCoastS, a thematic service to deliver wave and ocean circulation forecasts for the European Atlantic coast. The EOSC-Synergy project started in September 2019 aiming at harmonizing policies and federating relevant national research e-Infrastructures, scientific data and thematic services, bridging the gap between national initiatives and EOSC. The project is largely composed and coordinated by IBERGRID. LIP participates in the project management and contributes in the areas of software quality, services integration and digital repositories. In this context the group is also participating in the EOSC architecture working group. In the INDIGO-DC context, LIP continued to participate in the DEEPHybridDataCloud project which aims to develop technologies for large scale deep learning using cloud, HPC and hardware accelerators. LIP coordinates the software management and pilot infrastructure activities, and participates in several R&D activities related to accelerated computing and containers. The udocker tool development, maintenance and integration were supported by DEEPHybridDataCloud and EOSC--hub projects.

Advanced Computing

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

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

SPAC: Social Physics and Complexity

The Social Physics and Complexity has very recently joined LIP. SPAC uses large scale computational tools to study societal challenges, especially in disease forecasting, human behavior and public policy. This multidisciplinary research group takes advantage of the so-called “Big-Data Revolution” and works together to understand how individual behaviour impacts on society. We also focus on the risks that these technologies might entail and we help establish the guidelines for ethical uses of data science and artificial intelligence. The European Research Council has awarded a Starting Grant to the group PI to conduct the research project “Fake News and Real People – Using Big Data to Understand Human Behaviour (FARE)”.

Understanding complexity has always been a hallmark of physics research and, through theory, experiments, and models, physicists have made fundamental contributions to many different complex fields. Right now, the so-called Digital Revolution is offering radically new ways to study complex behaviours and this is being recognized by physics and computer science departments in many top universities worldwide. Complexity Science (CS) studies complex systems and tries to identify general principles. Complex systems consist of a large number of interacting heterogeneous components (parts, agents, humans etc.), resulting in highly non-linear and unpredictable behaviour, with emergence properties. CS theory typically builds on statistical physics and dynamical systems, but also on information theory and, increasingly, network science.

The combination of large-scale data sources and a growing toolbox from machine learning and big data analytics, is making it easier to extract patterns and offer some predictions. In fact, many of the methods developed by statistical and particle physics are now being applied to societies and there is a growing perception that physics will be fundamental to study sociology and even psychology. Leading scientists are calling this new science “Social Physics” and arguing that, in some ways, complexity science will study the physics of human interactions.

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Research Infrastructures

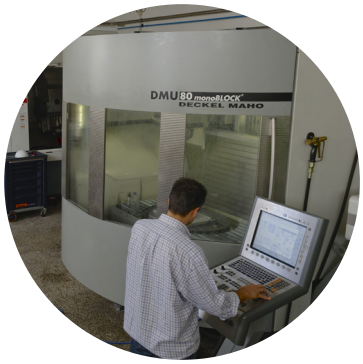
- Detectors laboratory
- Mechanical workshop
- e-CRLab
- LOMaC
- TagusLIP laboratory

Detectors Laboratory

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

In 2019, the main activities were related to the R&D and production of three different types of large area RPCs used in international projects in which LIP is involved: the particle physics experiments HADES and SHiP, the cosmic ray and muon tomography projects MARTA, MuTom and STRATOS, and the different ongoing medical imaging RPC-PET projects. Our contribution is multidisciplinary and spans from project design to the installation and maintenance of the detectors, development of tools and instruments to control/monitor the detector performance, and adapting the detector to the individual requirements of each application, following procedures that are similar to industry's. In 2019 we reached the101 RPC units built. We continued to improve the prototypes of a sealed RPC for the first time in 2019. The design is now stable and final, and two units have been produced and are under test.

A fundamental activity of the DL is to assist the groups in their R&D activities. We contributed with technical work and added value mostly to the following projects: RPC-PET, SNO+, HADES, Neutron detectors and Orthogonal Ray imaging, The DL has a major role in LIP outreach projects, namely the LIP spark chamber and the LIP cloud chamber. This year, we contributed to the cloud chamber upgrade, and the spark chamber production became a direct responsibility of the DL. Some improvements have been made that reduced the production cost by more than 30%. In addition, three new spark chambers were produced and two were repaired. Maintenance and upgrade tasks in both the DL and the MW were completed, and we continued to developed some work for the Physics and Chemistry departments of the University of Coimbra. A share of the work that is increasing is the one coming from direct contract for the provision of services and products by the DL to external clients, returning already considerable income.



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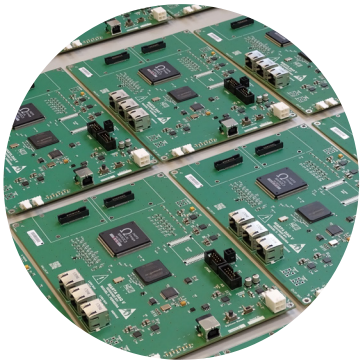
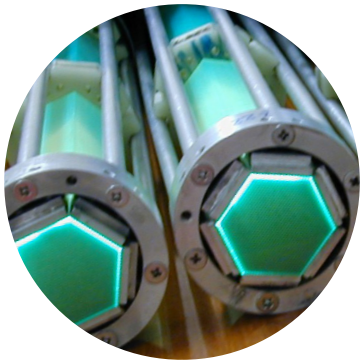
Mechanical Workshop

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

2019 has been a year with many projects and 100% of the time occupied. These included the conclusion of the construction, assembling and test of the second unit of the Umbilical Retrieval Mechanism (URM) for the calibration system of the SNO+ experiment; the construction of the HADES RPC forward detector prototype for in-beam measurements; construction of a chamber for testing new structures of gas amplification for the Gaseous Detector R&D group; construction of the mechanics for MUTOM tomography project; the construction of the mechanics for the first detector head of the HiRezBrainPET detector, for the development of a high resolution human brain RPC-based PET medical imaging device; the construction of the mechanics for two units of MARTA RPC detectors for the Pierre Auger Observatory.

Parts and pieces for many other groups were produced, namely for DL, LATTES, SHiP, RPC R&D, ATLAS, Portuguese Institute of Oncology, Chemistry Department, and other small works. Further work was developed for LIP outreach projects.The moving of the MW to the new location was completed, and maintenance and upgrade tasks were accomplished. A large area (3x2 m^2) CNC machine devoted to the construction of large area detectors was delivered at LIP in the first week of 2020.





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 2019, the e-CRLab has given a very large contribution to the MARTA project. The production and test of the front-end system has been done. The system was completely designed at the laboratory and the production outsourced. The e-CRLab had also the responsibility to design and produce support systems for the MARTA slow controls. The Central Unit of the system has been developed, based on a development board from Intel based on a hybrid system coupling a microprocessor to an FPGA (SOCFPGA). The monitoring and control system of MARTA has been developed and tested and is in commissioning phase. The acquired know-how was employed in several other activities that led to the development of experimental setups.

Firstly, in the context of the Pierre Auger Collaboration, muon hodoscopes were deployed using the MARTA DAQ and slow control, doubling the MARTA-test stand. Instrumentation of other hodoscopes for the Lousal Muon detector have been implemented, as well as test setup for SWGO/Lattes. The infrastructure has also developed work in radiation damage studies. With the Space Radiation group, we develop a small setup for the characterization of different components and their response to radiation. The understanding of the change in measurable parameters with radiation opens a possible R&D line of using COTS (Commercial Off The Shelf) components to measure the radiation field. This work, will be continued producing instruments to be tested under irradiation. The infrastructure has also developed work in the radiation damage studies. The know-how in the development of electronics has been used to give support to the development of electronics for the upgrade of ATLAS. The e-CRLab also provided support for teaching and outreach activities, mainly by developing and maintaining experimental setups.

LOMaC
(Laboratory of Optics and Scintillating Materials)

LOMaC's expertise is centered on the preparation and test of plastic wavelength shifter (WLS) and scintillating optical fibres, scintillators and related devices for high energy and nuclear physics detectors. LOMaC has facilities for cutting, polishing and aluminizing (by magnetron sputtering) bundles of optical fibres; automated devices for the characterisation and test of optical fibres, scintillators, and light sensors, and equipment to measure absolute light yield. LOMaC was created in the context of the ATLAS TileCal project in the 1990s, with human resources and expertise from CFNUL, LIP, FCUL, and UNL. The entire WLS fibres set for the TileCal has been polished, aluminized and quality controlled at LOMaC. Along the years, LOMaC selected and/or prepared optical fibres and scintillators for several experiments LIP was part of, including DELPHI, SNO+ and the ATLAS ALFA luminosity monitor. It gave crucial support to the development of the plastic profiles for the TileCal WLS fibres.

In 2019 LOMaC focused in: 1) TileCal and associated detectors; 2) Scintillator-based detectors for the Future Circular Collider (FCC); 3) Microdosimetry applications. The contribution for the ATLAS upgrade continued with the preparation of sets of WLS optical fibres for the Minimum Bias Trigger Scintillators (MBTS). Since the MBTS are located very close to the beam pipe, its scintillators suffer severe radiation damage. During the current shutdown, the most exposed were replaced by radiation harder ones developed at IHEP, Protvino. Ageing studies were performed using sets of fibres kept from the TileCal production for comparison. The measured attenuation lengths are compatible with the initial ones. Within experimental uncertainties of about 5% we do not see a significant transparency loss. For the fibre microdosimeter development, we have setup a new testbench to test ribbons of very thin scintillating fibres, and 0.5 and 0.25 mm diameter fibres were tested. For the FCC, scintillators used in detector R&D were tested with different light sensors. LOMaC has been extensively used in education and outreach. We participated in the LIP summer Internship Programme, hosting six students, three of them from Spain, the UK and Brazil.

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TagusLIP Laboratory

The TagusLIP Laboratory is a LIP research infrastructure installed in 2004 at the Lisbon Science and Technology Park. TagusLIP was conceived as a generic infrastructure for the development of radiation detectors with emphasis on nuclear medicine imaging technologies opened to external entities. The TagusLIP laboratory is equipped with the necessary instrumentation for R&D on radiation detectors and associated electronics and data acquisition, including electronics lab equipment, computing and networking systems. The laboratory offers software tools for developing analog and digital electronic integrated circuits, for firmware development, and for the design of printed circuit boards. The TagusLIP is licensed for the use of radiation sources needed to develop and test new instruments in nuclear medicine. The research teams that traditionally have been using TagusLIP have large experience in the development, commissioning and operation of large electronics and data acquisition systems in particle physics experiments and medical instruments. The development of TOFPET1 ASICs for PET Time-of-Flight applications was at the origin of the creation of the startup company PETsys Electronics in 2013.

In 2019 the main users of the TagusLIP Laboratory were the LIP-CMS research group and PETsys Electronics. On the LIP side, the activities concern the group's responsibilities on the Phase II Upgrade of the CMS experiment for HL-LHC, TOFHIR ASIC for the CMS MIP Timing Detector (MTD). The TOFHIR1 ASIC performance was tested using a dedicated system, SiPMs and laser light. A Front-End Board integrating 6 TOFHIR1 ASICs was developed and tested. The team is working on the development of the new TOFHIR2 ASIC, in collaboration with the PETsys team.

System simulations of the TOFHIR2 ASIC performance under the MTD operation conditions were conducted by the LIP-CMS team. PETsys Electronics is responsible for the microelectronics ASIC design, following the specifications of the LIP-CMS group, and the LIP group develops the integration of the chip in detector modules. As for PETsys Electronics, several of the other tasks concerned to the performance charaterisation of the ASIC TOFPET2 for special applications as requested by costumers, and also the work on its upgraded version. Several of the results obtained were presented at international conferences, including IEEE/NSS/MIC 2019 in Manchester.

Competence Centres

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

- Monitoring and Control
- Simulation and Big Data

COMPETENCE CENTRES

Monitoring and Control

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

In 2019, the CCMC developed activities both for other LIP groups and projects and for external entities. As a general tool, the CCMC continued the development of a complete software framework intended as the basis solution when deploying our products. The software was designed to be easily extended and interface with virtually any hardware used in monitoring and control, while at the same time supplying a user friendly front-end for displaying and manipulation of data.

Another highlight was the implementation of the temperature monitor and control system used during the test campaign (at Forschungszentrum Jülich) of the future TOF detector for the forward region of the HADES spectrometer. These tests aimed at characterizing the efficiency and timing accuracy of the detector as a function of its working temperature.

Concerning external entities, the main client was still the ECOTOP group from the MARE-UC institute. The CCMC performed with the field testing and final delivery of the non-invasive devices developed for the monitoring of the temperature and heart rate of seagulls during nesting in their natural habitat. We also developed and implemented the software to extract and process the information (e.g. filter ambient noise, detect the presence of seagulls in the nest) from the temperature and heart rate monitors. The CCMC also started the development and implement an improved version (version 2) of the measuring device, with improved autonomy and accuracy on the temperature measurement.

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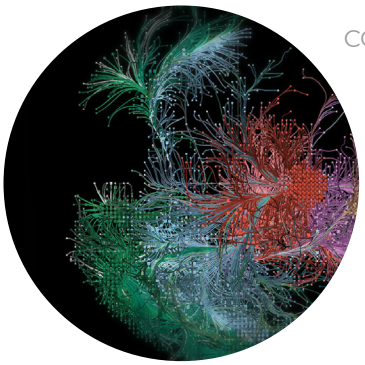

COMPETENCE CENTRES

Simulation and Big Data

The purpose of the Competence Center on Simulation and Big Data is the fostering of an effective collaboration between the LIP groups working on these areas and to boost the capability to exploit the existing expertise both internally and externally, towards the academy and industry. The different LIP groups have a vast range of competences in data analysis and simulation tools, including physics models, Monte Carlo generators, detector simulation tools, big-data handling techniques and data mining. The ability to fully benefit from such competences requires achieving critical mass, a coordinated training program, the exploitation of synergies between groups, and a clear identification of the key areas in which we can contribute in a competitive way. The competence center started its activities almost three years ago, but had a significant boost in 2019 with dedicated human resources, allowed by the obtained funding. For the immediate future the challenge is consolidation, and the expansion of the projects and connections with academia and society.

Simulation

In 2019, teaching of advanced detector simulation techniques as part of the curricula of specific undergraduate courses and doctoral programs was conducted. The participation in the Geant4 collaboration was continued, providing support and maintenance to one Advanced Example, for which LIP is responsible, namely in view of the last Geant4 release.Support to the needs of LIP research groups was provided. In particular, a close collaboration with muon tomography simulation activities was maintained. The participation of the LIP members responsible for the ANTS2 simulation tool in the activities of the competence center was strengthened, and work was developed in its interface and cross validation with GEANT4. Several developments were undertaken in the context of the specific activities of the LIP groups. The efforts towards a better integration of the activities and the collaboration between the different groups will be pursued..

Big Data

In 2018, the Big-Data branch of the competence center secured three funded projects in the big data area: FCT PTDC/FIS-PAR/29147/2017 BigDataHEP (started July 2018), COST action CA17137 (started September 2018) and STRONG-2020 (INFRAIA 01 Advanced Communities H2020 call, funding to start in 2019). The 1st School and Symposium "Data Science in (Astro)Particle Physics: the Bridge to Industry" was organized in Lisbon in March 2018.

Furthermore, regular informal meetings are held among all the interested LIP members, which include topical discussions and tutorials, and collaborations in the context of machine learning are ongoing between members of different LIP groups: ATLAS, CMS, Auger, LATTES, Dark Matter, Phenomenology.

In 2019, the Big-Data branch of the competence center performed the study and development of machine learning techniques for the detection of rare events at colliders, resulting in four publications, four completed master theses and several presentations in workshops. We organized the 2nd School and Symposium "Data Science in (Astro)Particle Physics and Cosmology: the Bridge to Industry", in Braga, in March 2019. A partnership was established with Nielsen, aiming to analyse data on their auditors. We pursued with the application of machine learning to analytical chemistry data to identify contaminants in printed circuit boards produced in industrial lines in the context of the iSci-Bosch-ECUM project. There are ongoing collaborations between members of different LIP groups (ATLAS, CMS, Auger, LATTES, Dark Matter, Phenomenology, SHiP) in the context of machine learning, including providing dedicated computing resources.

A collaboration with the gravitational waves community was established in the context of machine learning through the COST action CA17137, started in September 2018 and materialised, in 2019, in the co-organisation of the second edition of the school in data science, which included several participants from the gravitational wave community.

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Knowledge transfer and **societal impact**

Radiation, health and **environment**

SCIENCE AND SOCIETY

Advanced training

Education, communication and outreach

Knowledge transfer and societal impact

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

Portuguese official and industrial visits to CERN

The Minister of Science, Technology and Higher Education, the Secretary of State for Internationalization, and the President of the Foundation for Science and Technology (FCT) visited CERN in September 2019. The visit was accompanied by the Portuguese Delegate at the CERN Council and President of LIP, and by the Portuguese Ambassador to the United Nations in Geneva. The delegation included representatives from several other Portuguese institutions, namely universities, innovation, investment and internationalization agencies, and companies. We highlight the presence of the LIP Directorate and several LIP researchers, and of representatives of all our stakeholders. The visit aimed to reinforce the Portuguese presence at CERN in its scientific, technological and industrial aspects, in particular concerning the full exploitation of the opportunities to Portuguese companies created by the LHC accelerator.

Knowledge transfer and industry

Opportunities for knowledge transfer and collaborations with companies exist across the full spectrum of LIP's activities. Some highlights are given below:

Proton-therapy in Portugal
The installation in Portugal of a centre for proton therapy including both treatment and research facilities in the next few years constitutes a great opportunity. LIP is a founder member of the ProtoTera Association. It is our priority to promote the development of a national research network in advanced therapies and associated technologies to treat cancer patients, putting together a strong cooperation plan of the several LIP groups, with competence in related areas and working together with our partners. Funding has already been secured for two projects: a collaboration between the LIP OR-imaging group and a consortium led by PETsys, in the framework of the Portugal-Austin Program. Two further exploratory projects inolving the LIP Dosimetry and SpaceRad groups as well as the LOMaC facility have been prepared for the UTAustin Portugal Program 2019 Call for Exploratory Proposals.

RPC detector R&D
Both the RPC-PET project "HiRezBrainPET: neurofunctional cerebral imaging by high resolution positron emission tomography (PET)", (a partnership between the ICNAS-Produção Unipessoal, LIP and the Polytechnic Institute of Coimbra), and the production of sealed RPCs, able to work with no gas flux, are developments with the potential to change the paradigm in their areas. These are clear priorities for the near future. Previous consortia with industry have already been established in the context of using RPCs for muon tomography, mainly with HYDRONAV in the context of cargo container scanning.

LHC Upgrade
LIP is instrumental in creating opportunities for Portuguese industry at CERN and in other scientific infrastructures. In particular, the LHC upgrade constitutes a unique opportunity for collaboration between LIP and industry. In the High-Luminosity phase of the LHC physics program starting in 2027, the accelerator will provide an additional integrated luminosity of 3000 fb^{-1}over 10 years of operation. The work of the LIP CMS and ATLAS groups towards the Phase 2 Upgrade for operation at HL-LHC continued in full swing, following the signature in 2019 by FCT and the Minister of Science and Technology of the participation of LIP in the Phase 2 Upgrade of both experiments. Both ATLAS and CMS are collaborating with Portuguese companies in order to accomplish the tasks they are responsible for.

PETsys Electronics spin-off
The development of TOFPET1 ASICs for PET Time-of-Flight applications was at the origin of the creation of the start-up company PETsys Electronics in 2013. A technology transfer contract between LIP and PETsys Electronics was included in the process of creation of the company. PETsys Electronics has been using the TagusLIP infrastructure under the terms of a protocol established with LIP and was able in the past 6 years to develop considerably its activities and to become a main contender in the market of readout electronics for photosensors.

Space exploration
LIP's space activities are based upon collaboration with industry, contracts with the European Space Agency, participation in consortia for H2020 calls (currently EFACEC and EVOLEO).

The Portuguese Space Agency, PTSpace, which was created in 2019, was recently invited to join the NASA "International Space Exploration Coordination Group" (ISECG).

Computing
The LIP computing groups have extensive knowledge and experience in scientific computing, excellent international relations and integration in scientific e-infrastructures, with

users from multiple disciplines and organizations, participates in the FCT infrastructures, and in the enabling of future policies for scientific computing and open access. LIP co-leads the National Infrastructure for Distributed Computing, serving the Portuguese scientific community at large, and has growing expertise in data science and big data. This creates the potential for industrial and e-government applications, the possibility of engagement with other communities in addressing a number of societal challenges.

LIP's scientific infrastructures and competence centers
They provide support to LIP's activities, but also to external entities, through direct contract for the provision of services and products The purpose of the recently created LIP Competence Centers is to exploit the existing expertise both internally and externally, towards the university and industry.

Portuguese traineeship programme at CERN, ESA and ESO

Since several years LIP supports the FCT programme "Advanced training of engineers in the International Organizations - CERN, ESA and ESO", with a separated call for CERN since 2017. LIP encourages the groups at CERN to prepare and submit job description proposals (with a priority for the participation of Portuguese institutions and/or in key areas of interest to Portugal, as defined by FCT), helps disseminate the calls, and participates in the selection process of the candidates. A very positive feedback from the supervisors is testimony to the importance and success of this programme.

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, ELIALPS, ELI Beamlines, EPFL, ESS, GSI, IJS, IFIN-HH, INFN, Inovacentrum, KTN, LIP, NTUA, Sofia University, STFC, TU of Kosice, University of Belgrade, Weizman Institute and Wigner Research Centre; which work across a range of world leading scientific areas in the field of Particle Physics, Astrophysics and Nuclear Physics.

Radiation, health and environment

Radon measurements are currently the focus of activity of LIP's Radiation, Health and environment group. This radioactive gas, abundant in granitic areas, is recognized as a carcinogenic agent, and is signaled by the World Health Organization as the second leading cause of lung cancer after tobacco smoke. Knowing its concentrations inside houses is thus important from the point of view of radiological protection. In addition, Radon is the largest contributor for underground water radioactive pollution. Its concentration in water represents a public health risk due to the fact the gas can easily escape to the air, adding to the total radon indoor concentration. On the other hand, ingestion of water with a high radon concentration represents an additional risk for the stomach.

In 2019 the group focused in the study of radon gas in the air and water in certain regions of Angola and the study of radon exhalation. A study to measure the radon mass exhalation rate from common granite building materials used in the East and Northeast part of Portugal was carried out. Twelve cubic shaped samples were measured. Nine of them without any coating and three coated with different materials (varnish, hydrorepellent and liquid silicone). The radon measurements were performed with two different techniques: one using passive detectors and other using an active detector. For the passive method CR-39 solid state nuclear track detectors were used. The active method used the RAD7 DURRIDGE detector. Radon mass exhalation rates obtained from both methods present relatively low values for the analysed samples. Concerning the coated samples, the measured values are on average four times lower than the ones without coating. Overall the measured values for both methods present a good agreement. A new version of the radon monitor based on a low-cost photodiode with Arduino acquisition was build and tested. Two units are ready to be deployed in Angola.
Several international organizations involved in radiation protection and public health, have produced new guidance, recommendations and requirements aiming at a better protection from radon exposure. With the new legislation, DL 108/2018 (Transposition of Basic Safety Standards Council Directive 2013/59/EURATOM to national legislation) protection against indoor exposure to radon in both workplace and dwellings is clearly regulated and exposure to radon in dwellings is regulated for the first time. The LabExpoRad at Covilhã can provide radon measurement services for the community. For this, the certification of our laboratory services must be carried out.

// CONTACTS

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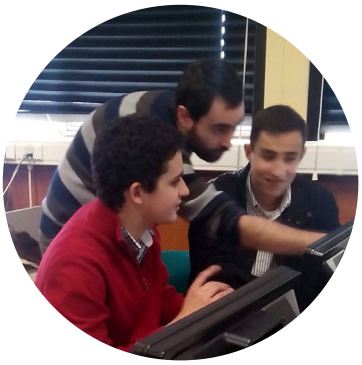

Advanced training

LIP has a long standing experience in advanced training, and permanently hosts tens of PhD, master and bachelor students, who actively work within LIP's research groups. In each of its three nodes, the Laboratory works in close relation and cooperation with the local universities. The capability to attract the best undergraduate and graduate students is central for LIP.

The advanced training group was created to coordinate and promote actions dedicated to university students at several levels (undergraduate, master, PhD). Its goals are:

- To engage undergraduate students: attract university students to learn about high-energy physics and be part of research at LIP, imparting the excitement of doing research in fundamental particle physics or advancing associated technologies in frontier experiments, and in the context of international collaborations.
- To ensure high-quality graduate training: support baseline core training and adequate guidance of LIP graduate students; support national and international PhD programmes and networks in our fields of activity.

Main events targeted at graduate and undergraduate students in 2019:

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

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

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

IDPASC student workshop, Braga, July 2019.

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

LIP Summer Student Programme, July-September 2019

Graduate students

Various actions are directed towards the PhD and master students working at LIP, and also in the framework of international PhD programmes. During 2019, LIP hosted over 80 graduate students. Furthermore, LIP coordinated the FCT doctoral programs IDPASC (Particle Physics, Astrophysics and Cosmology) and DAEPHYS (Doctorate in Applied Physics and Physics Engineering), and the IDPASC international network. LIP is a member of AMVA4NewPhysics, a EU funded International Training Network. The IDPASC international School: held in Otranto, Italy, and was jointly organized with the XXXI International Seminar of Nuclear and Subnuclear Physics "Francesco Romano". The school included lectures, discussion sessions and a final exam. Over 20 students participated. 5th LIP/IDPASC PhD Students Workshop was held in Braga. For two days, all students presented the status of their work to an audience of graduate students and researchers. Keynote lectures on selected topics were also part of the program, including transferable skill lectures on subjects suggested by the students themselves. In the framework of the LHC Physics Course, about 18 lectures covering introduction to the standard model, detectors, statistics, and overall research were proposed, from March through June. The course has a final evaluation and now gives credits to PhD students at IST. The course is addressed to a specialized/narrow set of master and PhD students. In 2019, three students completed the course and took the final exam.

A major event was the 2st School on Data Science in (Astro) Particle Physics. The event had the double goal of providing advanced training and establishing and consolidating links with other institutions and particularly with the non-academic sector through this field. The school had about 80 participants, and the symposium 114 participants, with representation from 20 companies. A public session was held by Glen Cowan (Royal Holloway) which was attended by over 100 people. This has now become a regular event series.

In December 2019, FCT and LIP signed an agreement for the new Portugal-CERN PhD grant programme in particle physics and related scientific and technological domains relevant for the Portuguese participation at CERN. The students should be enrolled in a PhD programme in these domains at a Portuguese university and hosted at LIP or at any R&D center with a protocol previously established with LIP.

Undergraduate students

The LIP summer Internship programme had in 2019 its third edition, and is now a well-established flagship event of LIP. All three LIP nodes were involved, in a total of over 60 students. The programme included a preparatory week (lectures and

hands-on tutorials), a research project of variable duration (up to two months), and a two-day final workshop in which the students presented their work. Lectures were complemented with thematic discussions, involving one researcher and few students. Also newly introduced this year were the so-called "August chats": informal gatherings where students briefly introduce themselves and their project and picked a specific problem or challenge to be discussed. Yet another novelty was the possibility offered to students to describe their work in a scientific paper with a prepared format, a challenge that was readily taken by several students. The programme counted on a broad participation of LIP researchers, who served as project supervisors, delivered tutorials and lectures, guides topical discussions, and attended the 2-day long final workshop.

Schools & workshops

LIP is involved in several regular school and workshop series directed at undergraduate students, which include lectures, hands-on exercises, and introductory overviews of ongoing research activity at LIP. In 2019, the 5th edition of the Lisbon mini-school in particle and astroparticle physics, co-organized by LIP and CFTP, was held in Costa da Caparica in February and gathered 30 undergraduate students from several universities. The 2019 Particles and Light hands-on workshop, held in July at FCUL and IST, counted with the participation of 11 students. The 2nd edition of the Data Science school and symposium was held at LIP-Minho in March, as described above.

Outreach for undergraduates

Besides training events, LIP conducts a number of initiatives with the goal of making LIP and particle physics known and attractive among undergraduate students. The LIP control room at IST is meant to be a meeting point between IST students and LIP researchers, mainly those teaching at IST but not exclusively. Sessions introducing detectors and physics topics have been held, and a display with LIP related news and announcements has been installed. Auger control shifts and CMS data quality shifts took place. Furthermore, LIP regularly participates in events organized by physics student associations at the different universities. In 2019, the National Physics Students gathering (ENEF'2019) took place at IST, and in this context over 60 students overall were received at LIP. In addition, 11 students from FCUL visited LIP. The visits were hosted by researchers from different groups, and further offered the opportunity for students to interact directly with master and PhD students at LIP.

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Education, communication and outreach

Education, Communication and Outreach (ECO) are today fundamental aspects of the activities of a research and development institution. This results from the recognition that ECO activities are both part of our social role and essential for the recognition of our work's relevance; and that such activities help attracting funds, partnerships, opportunities and human resources — both students and researchers.

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

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

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

2019 highlights

Project "SciCom with and for Students"

The goal is to involve LIP's PhD and master students in communication and outreach activities. The project gets the younger members of the different groups to work together, promoting communication and team spirit, while offering them volunteer science communication training. Feedback received indicates that young people can be very effective in communicating to school students. In the 2019 International Day of Women and Girls in Science, we invited high-school students and teachers to a public session presented by PhD and master students from LIP, with the title "Particles: from the Universe to the Laboratory".

European Researcher's Night

At Forum Braga, visitors built detectors and searched for particles in the city. At the Science Museum of the University of Coimbra, there was time to see cosmic rays and to learn about how positron emission tomography works. In Lisbon more than 150 participants, hosted at the Planetarium Calouste Gulbenkian, traveled to CERN on a virtual visit to the CMS experiment and saw particles passing in cloud chambers detectors.

LIP flagship initiatives for the school community

IPPOG's International Masterclasses in Particle Physics

Under the coordination of LIP, about 1700 participants gathered in 15 sessions all over the country: Aveiro, Beja, Braga (2 sessions), Bragança, Coimbra, Covilhã, Évora, Funchal (Madeira), Lisboa (2 places, 3 sessions), Ponta Delgada (Azores), Porto, Vila Real, and with our remote support in São Tomé and Príncipe.

Summer internships for high school students

In the framework of Ciência Viva's programme "Science in the Summer", LIP has proposed several internships in Lisboa and Coimbra and hosted close to 14 students to learn about experimental particle physics and directly experience the work of scientists in the field. Within the internship's programme of the University of Coimbra, LIP further hosted 13 students for one week in internships devoted to the ATLAS experiment at the LHC and to dark matter searches.

CERN Portuguese Language Teachers Programme

Under the responsibility of LIP and with support from CERN and Ciência Viva, the 13th edition of the school was held in the beginning of September, attended by 20 Portuguese teachers, 20 Brazilian teachers and two Angolan teachers. In this edition, it was again not possible to obtain enough support to bring more teachers from Portuguese-speaking African countries. Efforts to re-establish this participation in the next editions will be continued. Over the last decade, more than 720 teachers attended the school. An online survey was conducted, which was used as the basis for conference presentations and has shown a high level of appreciation.

Seminars in schools

More than 70 outreach talks were given by LIP scientists in schools, mainly in the areas of Braga, Coimbra and Lisboa but also occasionally in other places. The creation of a list of talks proposed to schools, available on the outreach section of the LIP website, allowed for a greater diversify of subjects and speakers that actually go to schools, and to have more schools into the loop.

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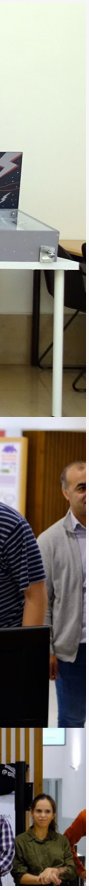

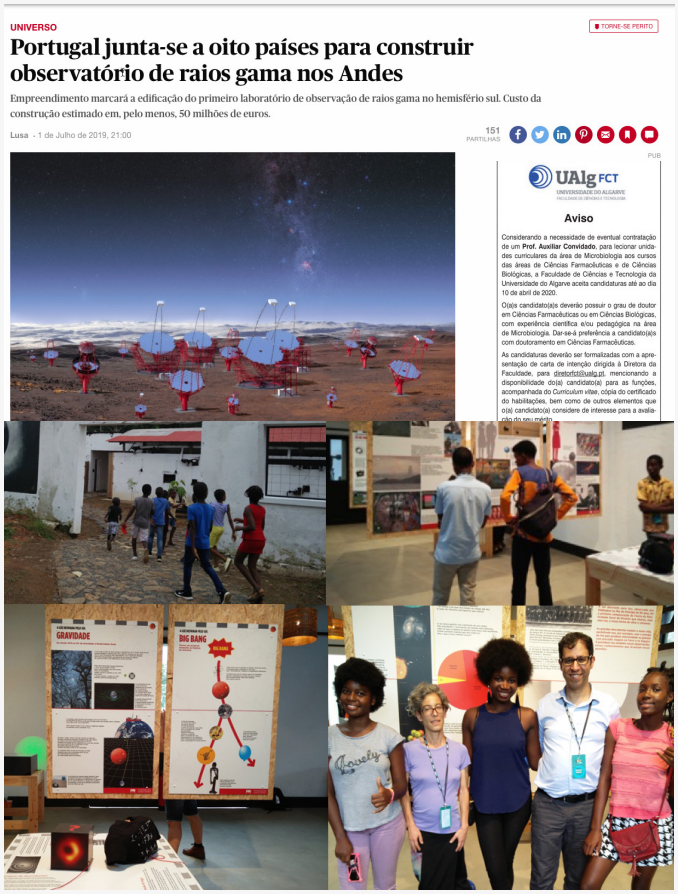

UNIVERSO

TORNE-SE PERITO

Portugal junta-se a oito países para construir observatório de raios gama nos Andes

Empreendimento marcará a edificação do primeiro laboratório de observação de raios gama no hemisfério sul. Custo da construção estimado em, pelo menos, 50 milhões de euros.

Lusa · 1 de Julho de 2019, 21:00

151 PARTILHAS

PUB

UAlg FCT UNIVERSIDADE DO ALGARVE

Aviso

Considerando a necessidade de eventual contratação de um **Prof. Auxiliar Convidado**, para lecionar unidades curriculares da área de Microbiologia aos cursos das áreas de Ciências Farmacêuticas e de Ciências Biológicas, a Faculdade de Ciências e Tecnologia da Universidade do Algarve aceita candidaturas até ao dia 10 de abril de 2020.

O(a)s candidato(a)s deverão possuir o grau de doutor em Ciências Farmacêuticas ou em Ciências Biológicas, com experiência científica e/ou pedagógica na área de Microbiologia. Dar-se-á preferência a candidato(a)s com doutoramento em Ciências Farmacêuticas.

As candidaturas deverão ser formalizadas com a apresentação de carta de intenção dirigida à Diretora da Faculdade, para diretorfct@ualg.pt, mencionando a disponibilidade do(a) candidato(a) para as funções, acompanhada do Curriculum vitae, cópia do certificado de habilitações, bem como de outros elementos que o(a) candidato(a) considere de interesse para a avaliação do seu mérito.

In the media

Although this is not chosen as a priority, we profit from the opportunities related directly to LIP or to CERN and the experiments we are part of. Most articles came out in LUSA (the national news agency) and Público (a reference national daily newspaper). LIP also participated several times on "90 seconds of science", a daily science broadcast on a national radio channel.

Eddington's observations centenary

Together with the Portuguese Physical Society, LIP updated and developed new modules for the exhibition "The light deviated by the Sun", inaugurated in the framework of the Eddington@Sundy innitiavive to celebrate the centenary of the experimental proof of General Relativity, and will be the basis of a permanent science centre in Príncipe island. In São Tomé, LIP has participated in the 3rd Physics Conference of the Community of Portuguese Speaking Countries, LIP is a collective associate of SPF, and several of its members serve in the management, as conveners of the Particle Physics Division, or contribute on a regular basis to SPF's magazine.

LABORATÓRIO DE INSTRUMENTAÇÃO
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