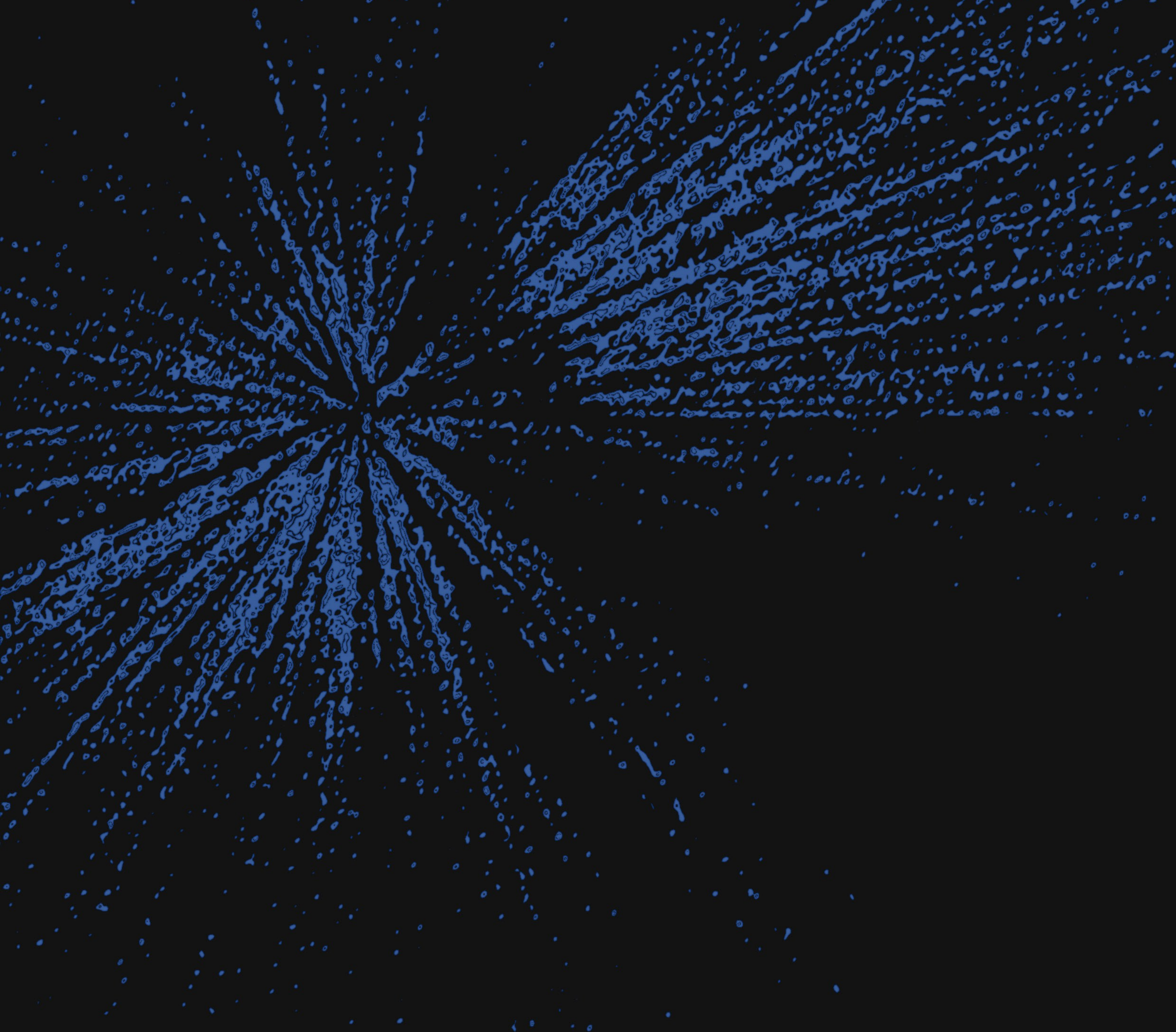
annual report

2020/2021



LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

partículas e tecnologia

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LIP is about Particles, Technology and People

LIP, Laboratory of Instrumentation and Experimental Particle Physics, is the reference institution for experimental particle physics and associated technologies in Portugal. It was founded in May 1986 to exploit the unique opportunities created by the country's accession to CERN, the European particle physics laboratory. LIP brought experimental particle physics in Portugal to a truly international ground and will continue leading this challenge..

LIP is devoted to research in experimental particle physics and associated technologies, enhancing the direct access of the Portuguese scientific community to international infrastructures and collaborations. At the centre of our mission are also scientific computing, advanced scientific and technical training and the engagement of society with science. Opportunities of knowledge and technology transfer to society are also explored, in domains such as health, space exploration and information technologies.

LIP

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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 Lisbon, 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 Lisbon, 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).

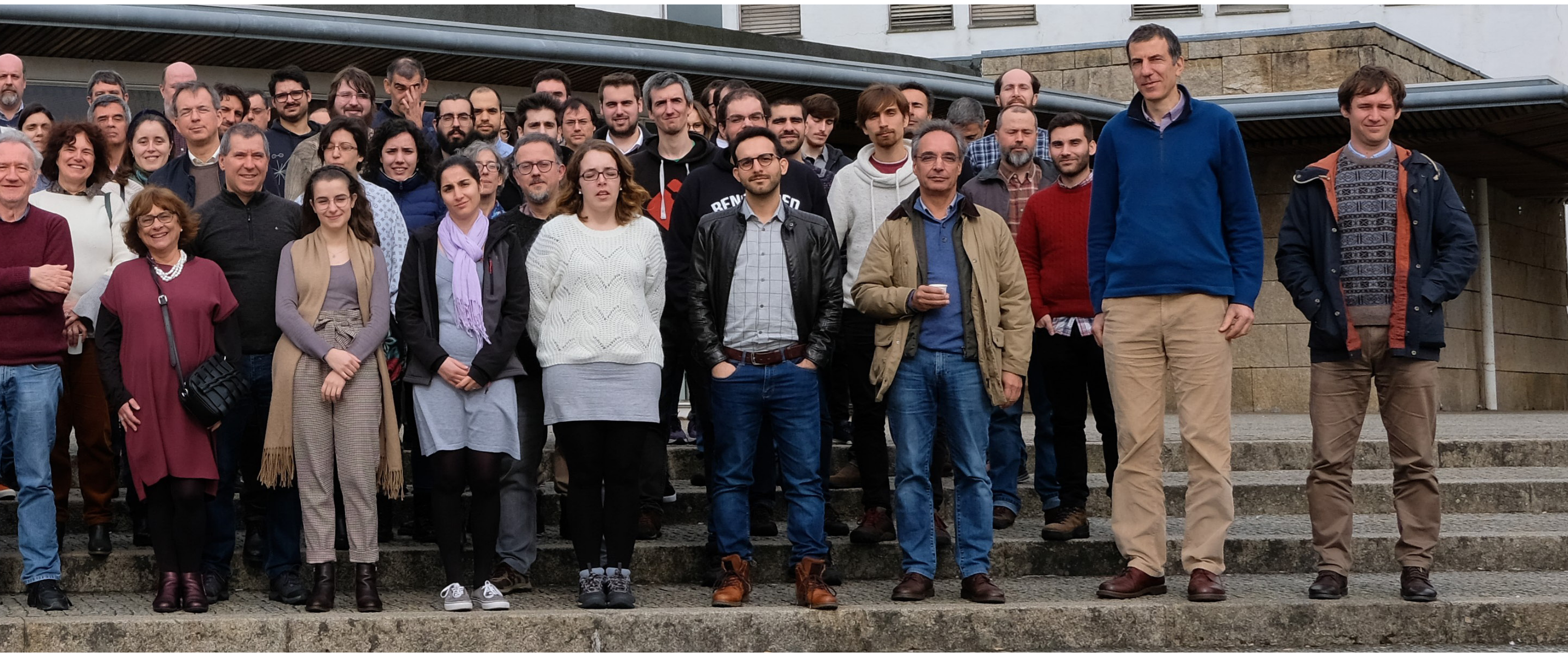
The three pillars of activity at LIP are:

- Discovery through science: LIP's programme in 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.

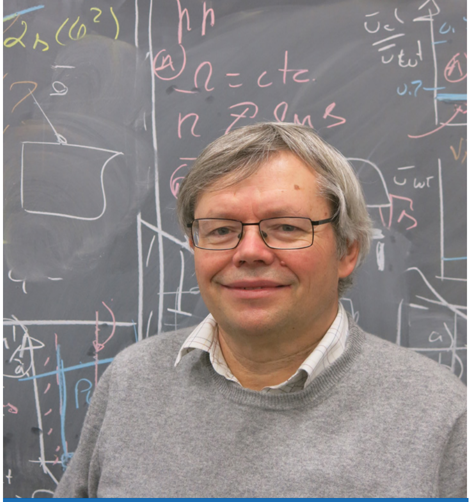
LIP is deeply involved in the CERN Large Hadron Collider (LHC) programme, contributing from the very beginning to the two largest LHC experiments, ATLAS and CMS, and exploring new physics phenomenology. LIP is also involved in the fixed target programmes at CERN and GSI, probing the strong nuclear force 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.



prof.
Mário Pimenta
President

Foreword

Uncertainty & opportunities

We are living in strange times, where the future may change radically every day; times of uncertainty, times of opportunities...

LIP was able to adapt itself to the difficult and stressful work conditions of this past year; trying to help society as much as possible in the first moments when a lack of medical and sanitary equipment was a reality, with initiatives like the design and construction of low-cost, technically easy to implement, ventilator prototypes for COVID-19 emergency clinical intensive care, as well as producing face shields for health professionals in nearby hospitals; trying to keep "business almost as usual" with a massive use of tele-working and, whenever physical presence was essential and allowed, strictly complying with the recommendations and rules from the Universities and Health authorities.

We all have the feeling of an almost lost year but, in fact, the World didn´t stop. Relevant moments for our future were, for instance: the approval of the European Strategy for Particle Physics (ESPP) by the CERN Council; the evaluation by the FCT of the Associated Laboratories; the start of activity of the ProtoTera association.

The ESPP will have a central role in the future of our domain. In the short and medium-term, priority is given to the completion and exploitation of the High-Luminosity LHC, but keeping always in mind that the post-LHC era will come soon enough, which implies, already now, launching a huge scientific, technical, political and societal effort. The precision (Higgs factory) and the energy (100 TeV) frontiers are the top priorities, which may be attainable with the construction of the Future Circular Collider (FCC) at CERN. In parallel, it was strongly recommended to maintain the European support for neutrino physics, astroparticle and nuclear physics, as well as, to increasingly pay attention to societal aspects, such as training and knowledge transfer, and to the minimisation of the environmental footprint.
Portugal, LIP and the remaining Portuguese particle physics community have actively followed and participated in this two-year long process and are fully engaged in its successful realization, maintaining European leadership in science, technology and engineering and contributing to a better and peaceful world, as stated in the CERN convention, signed in the fallout of the massively destructive second World War.

A new cycle of evaluation of the Associated Laboratories in Portugal took place during 2020 and should be concluded soon. The defined priorities were: the contribution to public policies; the capability to create and sustain permanent scientific employment; increasing the degree of internationalization and the capability to attract international talent and funding. The goal of this evaluation was not to rate the scientific performance of the institutions, which had been the object of the research units evaluation, held two years before, in which LIP was classified as Excellent. The positive aspect of the evaluation process for LIP was that the jury, composed exclusively of Portuguese members, recommended that LIP should remain as an Associated Laboratory keeping the same level of funding. However, we deeply disagree with the overall appreciation of the Jury, which was basically centred on the ability to obtain external funds. External funding is undeniably an important factor, but such ability must necessarily be assessed in the context of the scientific activity developed by each Laboratory.

LIP is a Laboratory whose main object is fundamental science, and whose first mission is the development of High Energy Physics in Portugal, namely ensuring Portugal's successful participation in CERN and in other large international scientific infrastructures. It is well known, although ignored by the Jury, that CERN's financing model relies essentially on the contribution of national funding agencies. This model has no parallel in other institutions with international projection, whose financing is ensured through the transfer of EU funds. Nonetheless, LIP has been in a sustained path towards reducing its dependence on direct funding from FCT, by increasing the much-desired international funding. Both our path and the new funding already secured, increasing the international funding level from 10% of the total budget to 15% already in 2021, were sadly ignored.

Globally, the number of recommended Associated Laboratories was 40, while previously only 26 had this status, whose individual funding was kept basically the same. Nobody was really satisfied with the outcome, as the general expectations were much higher. Furthermore, there is still no apparent consensus on what should be the model that ensures a medium and long-term sustainable future for the Associated Laboratories, according to their own specificities, nor there is a consensus on the corresponding creation, at appropriate levels, of the much-needed scientific employment. Universities should be part of the solution, but this is even more difficult and complex. Anyhow, we should all be acutely aware that we must continuously demonstrate the scientific, technological and societal impacts of our activities. Both to society at large and also to the Portuguese scientific community in domains a priori further away from ours.

ProtoTera, the Portuguese Association for Proton Therapy and Advanced Technologies for Cancer Prevention and Treatment, was formally created in December 2020. The association started its activity during the COVID-19 pandemic crisis. Its first goal is the development of infrastructures for the treatment of cancer patients and for cancer research. It will use proton beams with energies of 250 MeV and 70 MeV, respectively, in Loures (in an extension of the CTN/IST campus) and in Coimbra (in the ICNAS/UC premises). The Loures unit will have 2 or 3 general purpose treatment rooms and 1 research room, while the Coimbra unit will be dedicated to the treatment of ocular melanoma and to the production of new radioisotopes for medical applications. The medical coordination and the patient screening and selection will be coordinated by the Grupo Hospitalar Instituto Português de Oncologia Francisco Gentil (GHIPOFG) which is, with IST, UC and LIP, a founder of the ProtoTera association. In parallel, ProtoTera has the mission to develop postgraduate education and training actions for medical and non-medical specialists, namely physicians, physicists, engineers and medical physicists, to build-up the required pool of skilled specialists for the treatment and research programs.

One year after, where do we stand? The requirements and technical specifications for the proton therapy unit in Loures are well advanced and practically ready to be submitted to the international advisory committee that was meanwhile constituted. In Coimbra, the best design options are under study, in collaboration with CERN, to provide intense beams and lower energy for radioisotope production, or higher energy and low intensity beams for eye treatment. The detailed implementation plan for the Loures infrastructure is being discussed with the Loures municipality and is in an almost final version. The major items of the business plan were identified, and the corresponding studies should be carried out until the end of the current year. Funding opportunities were explored but not yet secured. A PhD grant program in the areas of medicine, technology and physics, that will support the installation and operation in Portugal of cancer treatment centres using proton beam therapy, was launched in collaboration with FCT. Up to 5 grants per semester may be awarded and the program is already in its second call.

Internally, the periodic evaluation of LIP's technical and administrative staff by the LIP management finally started and its first edition is almost concluded. As a result, there was a well -deserved salary progression of many of the LIP employees. In parallel, the evaluation of LIP researchers by the LIP scientific council is reaching the conclusion of its second edition. The procedures for the recruitment of researchers for permanent positions at LIP, either by competitive and open international calls or as the result of the awarding of an ERC grant or of two FCT individual research grants, were established and clarified. As a result, five new permanent positions were awarded at LIP. These actions represent an important effort by LIP to provide better and fair working conditions to its researchers, engineers, technicians and administrative staff. However, a reasonable solution of the structural problem of scientific employment in the Portuguese scientific system will only be possible as a result of combined and coordinated efforts of the research institutions, FCT and the Universities. Finding such lasting solutions will demand, for sure, an increase in the public investment in science in years to come. But it will also require a clear effort of the scientific institutions to diversify and increase their funding sources within their own capabilities and specificities. At LIP, we set as our goal to double our external funding by the end of the period 2021-2025, as compared to our average external funding during the previous five years.

LIP education and training actions were pursued, as much as possible within the external constrains. The highlight was the start of the PT-CERN PhD grant program in particle and astroparticle physics and related scientific and technological domains. This program is in line with an already long collaboration between FCT and LIP in such programs, namely in the framework of the IDPASC PhD program network. It should also be mentioned the continuation of the LIP summer internship programme, this time necessarily adapted to the pandemic conditions, which allowed to integrate for some months in LIP's activities a significant number of students from Portuguese and international Universities.

On the coming 9th of May LIP will commemorate its 35th anniversary. We had already many cycles of life, under better or worse external circumstances, with more optimistic or pessimistic evolution scenarios in Portugal and in the World. Every day a new cycle begins, and new and greater challenges, opportunities and responsibilities are facing us. As in the past, all together, and with an increasing number of strategic national and international partnerships and an increasing connection to society, we will be able to go on fulfilling our missions.

(Mário Pimenta)

Lisbon, March 2021

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 Electronics and Computing for Physics 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 29th and 30th April 2021 by videoconferencing. Prior to the meeting, the Committee had received extensive and well-prepared documentation about the LIP activities and a copy of the slides to be shown. Oral presentations and discussions during the meeting provided further clarifying information.

The meeting started with a tribute to Armando Policarpo, one of the founders of LIP, who passed away recently.

LIP's primary mission is the study of the fundamental laws of particle physics. This research is carried out presently with accelerators at CERN, where LIP has an important role in the two large experiments, ATLAS and CMS at the LHC and in COMPASS at the SPS. Neutrinos are investigated with SNO+ in Canada. Research on cosmic rays and their astrophysics implications is carried out 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 the US. LIP participates in these research programmes as a partner in large international scientific collaborations, with many leading positions and major responsibilities. LIP's scientific contributions within the collaborations are outstanding. The LIP theory groups are very productive and participate in the interpretation of the results obtained by the experimental groups.

LIP is strongly engaged in preparing future experiments. LIP teams have made significant progress in R&D, design and prototyping for the High-Luminosity LHC upgrade of ATLAS and CMS detectors and are now implementing the upgrades. R&D, design, prototyping and testing are also pursued for the DUNE neutrino experiment in preparation in the USA and for the preparatory phase of proto-DUNE at CERN. LIP is among the proponents of the new SHiP facility at CERN and is prototyping some components of the proposed detector. LIP also participates in the recently approved SHiP-inspired innovative neutrino experiment SND at the LHC. LIP is a key promoter of SWGO, a novel ground-based array in the Southern hemisphere for high-energy gamma ray astronomy, which is now evaluating two possible conceptual designs.

LIP has a continuing and growing engagement in activities with a direct and positive impact on society, relying on the competence of individuals and teams, such as particle detector R&D and construction techniques, electronics and computing. LIP's development of novel medical imaging instrumentation for diagnostics or image-guided radiation therapy is promising. The Committee strongly supports LIP's major role in driving ProtoTera and the related efforts to expand its research portfolio into interdisciplinary activities at the interface between physics and biology. LIP's contributions are essential for the success of the project.

During the pandemic LIP has helped by designing and constructing medical equipment and in data analysis of the disease propagation. LIP also makes significant contributions to important programs in terrestrial and space radiation simulation and in 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. The engagement of LIP computing teams in international collaborations has continued successfully during 2020.

LIP is growing and is enlarging its scope by federating institutions and groups with activities related to LIP. The joining of new groups in recent years strengthened areas such as theoretical and nuclear physics and computing. In 2020 the integration of the SPAC group (Social Physics and Complexity) has been successful and brought profitable synergies. The Committee strongly supports this strategy, which no doubt is advantageous for science in Portugal.

The Committee acknowledges the success of the Competence Centers, not only as a means of increasing competence and cohesion of LIP staff but also as an opening to other fields of science and to industry. The Committee sees potential for further progress and encourages the groups to actively pursue their missions.

LIP is aware of the importance of communicating science to society. Its staff is fully engaged in innovative outreach activities, with emphasis on attracting students to science and to particle physics in particular, through seminars, masterclasses, internships and summer courses. The Committee considers this activity exceptionally good compared to international standards.

The Committee noted repeatedly the remarkably diverse research and R&D activities and encouraged the LIP Management to continue their efforts in sharpening the focus. This is particularly relevant for activities related to ProtoTera, which will provide and require to further structure LIP's activities in areas, such as instrumentation for medical imaging and dosimetry. LIP must seek timely input from the clinical and biologist end-users, where appropriate. The Committee applauds the progress achieved to date and encourages the LIP Management to vigorously pursue these lines of convergence.

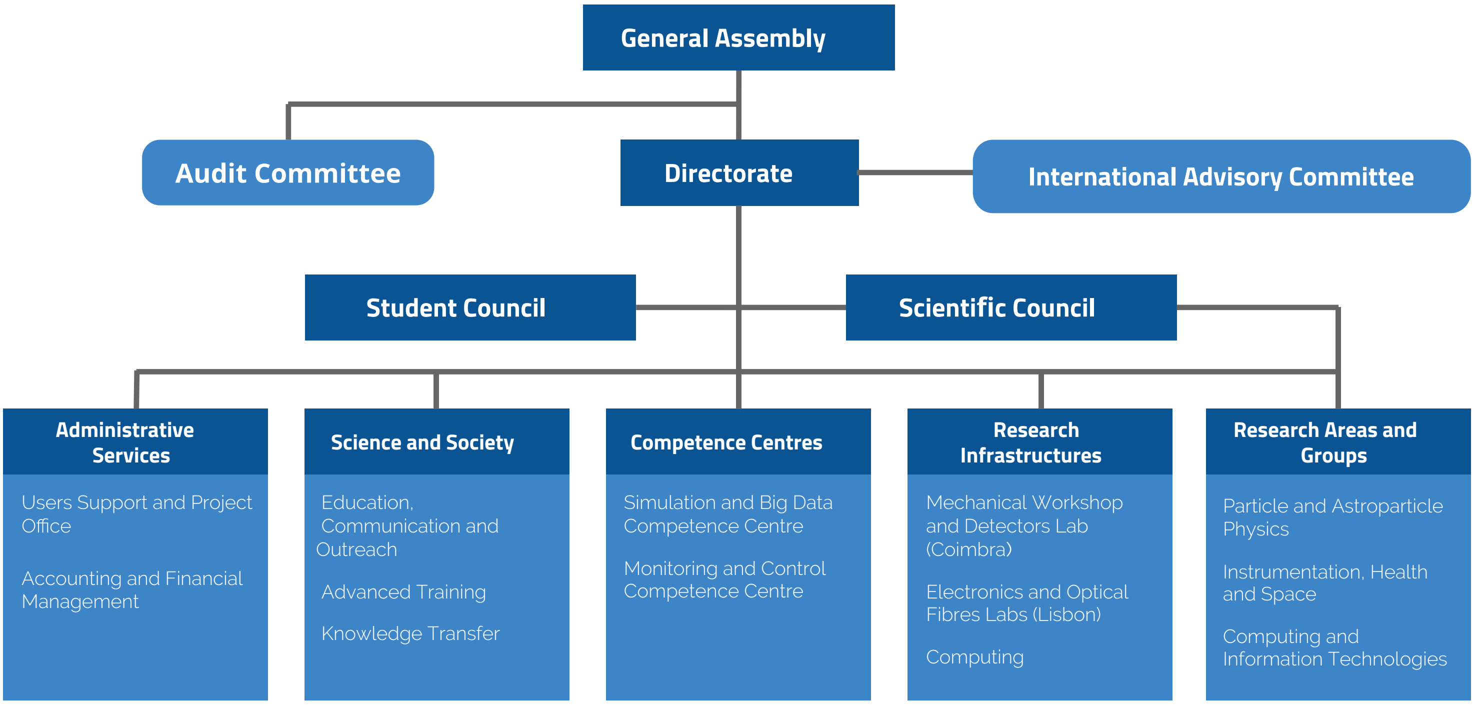
An institution like LIP will always carefully pay attention to the employment situation. The Committee was pleased to learn that LIP was able to make further progress in consolidating some employment positions during last year and has exceeded the level of 100 integrated researchers. The Committee supports LIP's effort towards further improvement, in particular the ratio of permanent to fixed-term staff In the view of the Committee a plan would be helpful, which motivates and aligns the planned staff evolution with LIP's future research agenda. The Committee also noted the changing landscape for financial support, relying increasingly on very competitive applications for EU-funded projects. A very welcome step was the recent establishment of an office to support LIP staff in preparing such applications. Attracting and mentoring M.Sc. and Ph.D. students is vital. The Committee again strongly encourages LIP to establish formal mentoring and supervising procedures for all students. Further steps can be taken for increasing visibility and attractiveness of the various student programmes.

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 of important LIP activities.

The Committee wishes to emphasize that despite the constraints and obstacles brought about by the COVID pandemic the performance of LIP in the past year has been excellent. It congratulates the LIP Management and the LIP staff for their achievements.

Structure & 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.

Administrative services

The LIP community has the support of a small but effective group of administrative staff (seven elements in Lisbon and two in Coimbra) split in the following services: Users Support and Project Office; Accounting and Financial Management. The Project Office has recently been reinforced with a new member dedicated particularly to assisting researchers with preparation of proposals (pre-award). The goal is to strengthen LIP's capacity to attract international funding.

Science and Society

The Education, Communication and Outreach (ECO), Advanced Training (AT) and Knowledge Transfer (KT) groups are dedicated support structures reinforcing the link to society. The ECO group deals both with institutional communication, both internal and external, and with LIP's broad programme for the school community. The AT group engages with undergraduate and graduate students through the organization of schools, workshops, internships and other events, and oversees the hosting and training condition of PhD and master students at LIP. The KT group maintains a close connection with CERN-related KT bodies, FCT and ANI.

Highlights of the year 2020

January

- Creation of the Portugal - CERN PhD Grant programme, by agreement between FCT and LIP
- Bad Honnef meeting marks the final discussions for the update of the European Strategy for Particle Physics

February

- Ksenia Shchelina and Tahereh Niknejad receive CMS awards, announced during the CMS week at CERN
- DUNE Collaboration announced the publication of Technical Design Report
- LIP-Minho celebrates 10 years of existence
- "Jornadas do LIP", LIP's general biennial scientific meeting, was held in Braga
- 5th edition of the Lisbon mini-school in Particle and Astroparticle Physics, jointly organized by LIP and CFTP
- The first Geant4 course organized by the LIP Simulation & Big Data Competence Center took place in Braga

March

- COVID-19 pandemic: first lockdown in Portugal starts in mid-March; most LIP members start working remotely
- Galaxy service @EOSC-synergy made available for SARS-CoV-2 studies
- 10 years since the first high-energy collisions at the LHC, on March 30, 2010

April

- A team at LIP-Coimbra develops an emergency ventilator for COVID-19 within #ProjectOpenAir
- COVID-19 protection visors for healthcare professionals have been developed at LIP-Coimbra
- First fully virtual Master thesis defense (LIP student Ricardo Barrué, at IST)

May

- La Caixa Foundation Postdoctoral Junior Leader contract given to Inês Ochoa, joined the LIP ATLAS group
- SNO+ renewed as CERN recognized experiment (RE35) for another 3 years
- LIP members take SNO+ in telework mode, controlling the detector from home (untethered shifts)
- LIP's 34th Anniversary is celebrated on 9 May
- A Portuguese team is shortlisted in the "Beamline for Schools" competition
- 8th LHC Physics Conference takes place online

June

- Launching of tribute website to Gaspar Barreira (1940-2019)
- First observation of Bs meson in nuclear collisions reported by CMS
- Hard Probes 2020 takes place online, with about 700 participants
- CERN Council unanimously adopted the update of the European Strategy for Particle Physics
- LIP was twice on the "90 seconds of Science" radio broadcast, with L. Apolinário and P. Assis, and again in September with R. Barrué

July

- Session "Portugal-CERN-Europe: Science and technologies in the coming decades" at CTN marked the approval of the European Strategy for Particle Physics Update.
- Start of the 2020 LIP Internship Program
- Start of the Ciência Viva Summer internships for high-school students at LIP
- Integration Progress Review of STRATOSPOLCA student project by ESA's BEXUS program members in Coimbra

August

- 40th International Conference on High Energy Physics is held online from 28 July to 6 August.
- Helena Santos appointed as run coordinator of the ATLAS TileCal

September

- Letter of intent for the installation at the LHC of a neutrino detector developed for the SHiP experiment
- Issue #17 of the LIP-news Bulletin published
- 2020 National Physics Meeting, organized by SPF. LIP and Particle Physics were represented in several ways
- Final workshop of the LIP Internship Programme
- CERN publishes first public Environmental Report
- Start of the European projects in high performance computing EuroCC, in which LIP is involved

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
- Start of the ERC project FARE

November

- "Particle Physics for the Future of Europe" meeting gathered the particle physics community in Portugal to discuss the European Strategy for this domain recently approved by the CERN Council
- First observation of top quarks in heavy ion collision announced by CMS. The analysis was motivated by a theoretical paper co-authored by researchers in the LIP Phenomenology group
- Ciência Viva programme "Space goes to school" takes LIP researchers to several schools (mostly virtually)

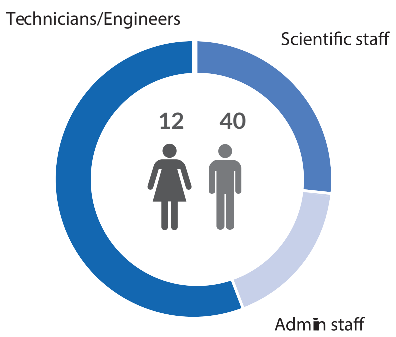
December

- Ana Luísa Carvalho, PhD student in the LIP ATLAS Group, is one of the winners of the ATLAS PhD Grants
- The AeroClean air sterilizer co-developed by a LIP member in the fight agains COVID-19 started working in a Brazilian hospital
- CERN announces a new Open Data policy, unanimously endorsed by the four LHC collaborations

LIP in numbers

Human Resources

STAFF



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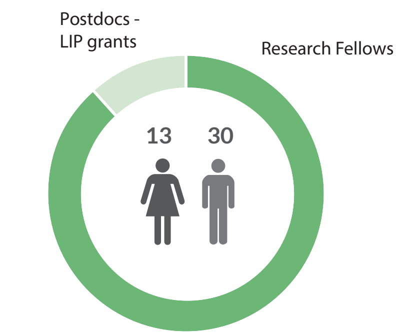
52
TOTAL

Technicians/ Engineers	2	27
Scientific staff	2	12
Admin staff	8	1

FIXED-TERM RESEARCHERS



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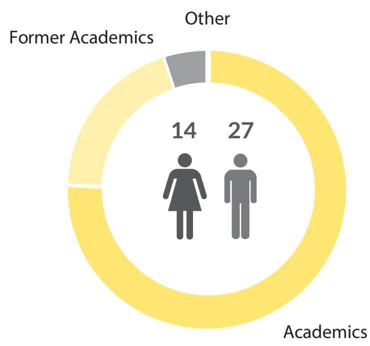
43
TOTAL

Research Fellows	12	26
Postdocs LIP grants	1	4
Postdocs other grants	0	0

UNPAID



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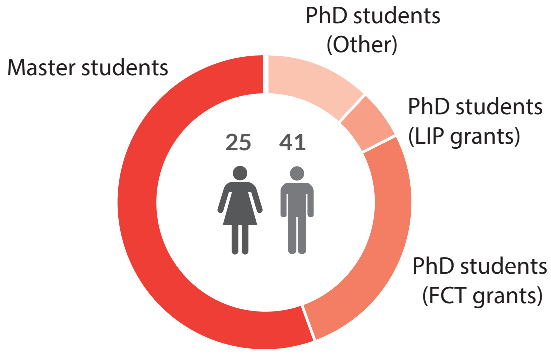
41
TOTAL

Academics	9	22
Former Academics	4	4
Other	1	1

TOTAL
202

64 138

STUDENTS



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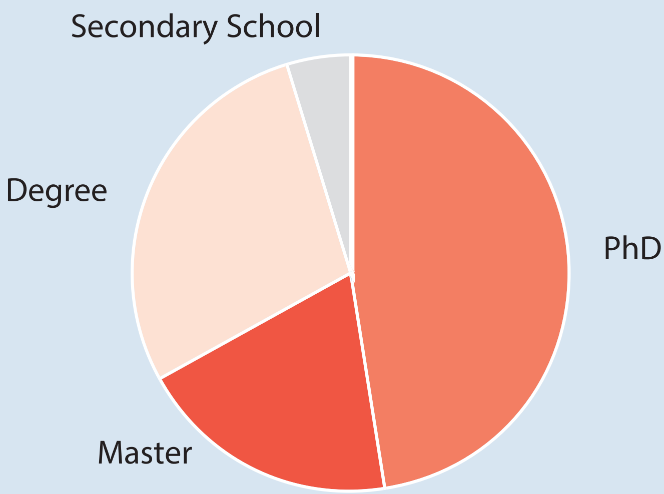
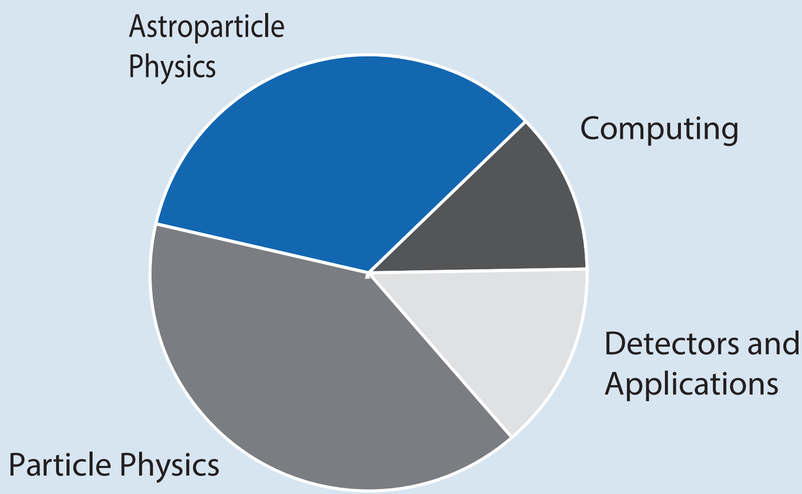
66
TOTAL

Master students	12	21
PhD students FCT grants	8	12
PhD students LIP grants	0	4
PhD students Other	5	4

DISTRIBUTION BY ACADEMIC QUALIFICATION

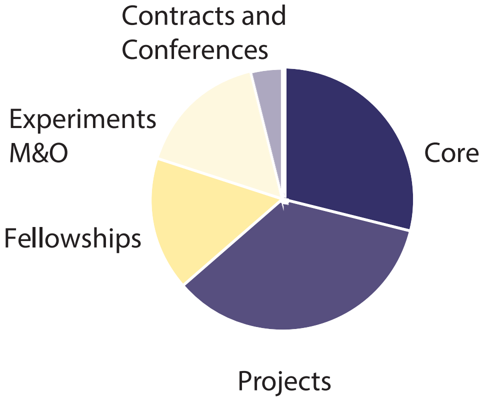


DISTRIBUTION BY RESEARCH AREA



Finances

GENERAL FUNDING



1.6M
CORE FUNDING

1.9M
PROJECT-BASED

0.9M
FELLOWSHIPS

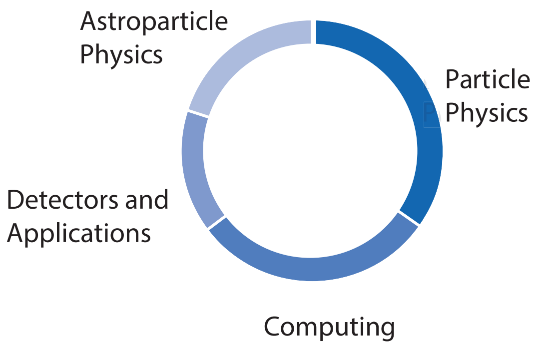
0.9M
EXPERIMENTS M&O

0.2M
CONTRACTS AND CONFERENCES

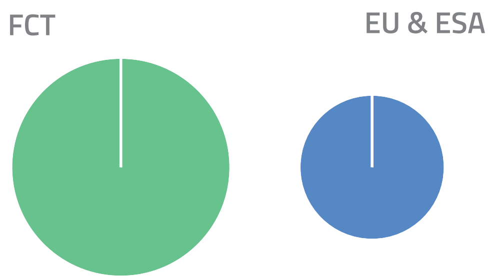
TOTAL
5.5M €

PROJECT AND CONTRACT-BASED FUNDING

BY RESEARCH AREA

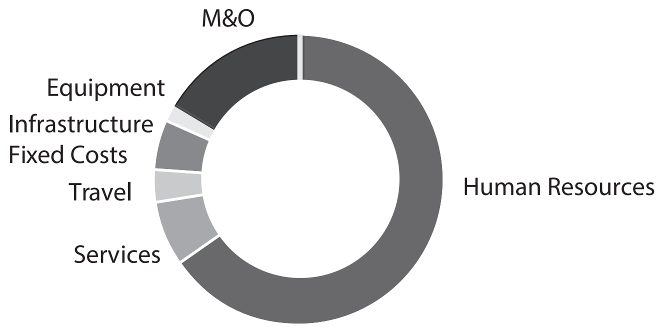


BY ORIGIN



TOTAL
1.9M €

COSTS



HUMAN RESOURCES

STAFF 1.9M

FIXED-TERM RESEARCHERS 1.7M

SERVICES AND OTHER EXPENSES

0.4M

TRAVEL

0.2M

EXPERIMENTS M&O

0.9M

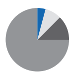
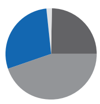
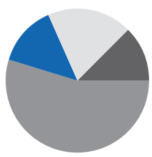
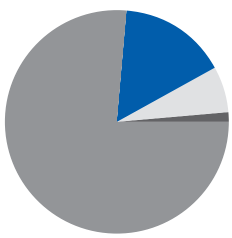
INFRASTRUCTURE FIXED COSTS

0.3M

EQUIPMENT

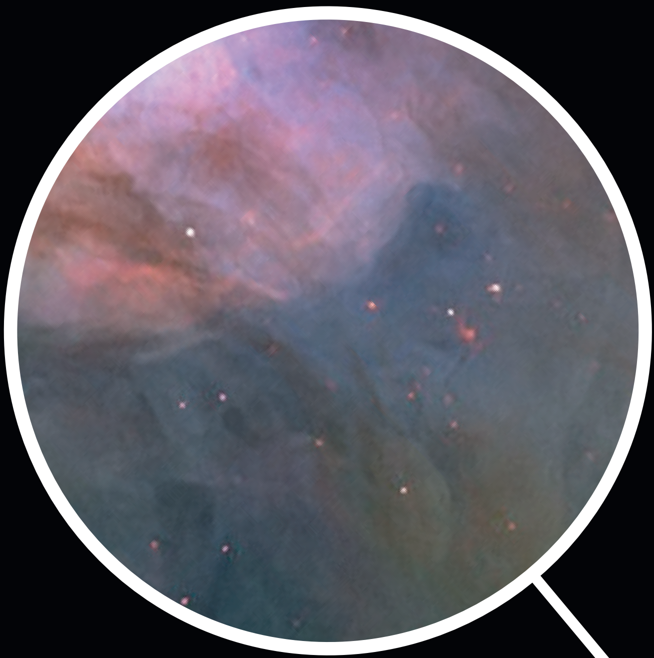
0.1M

Scientific 2020 output

		Particle Physics	Astroparticle Physic
Books, Reports and Proposals		1	3
PhD Theses		2	2
Master Theses		7	4
Proceedings		18	1
Notes		22	14
Presentations		150	37
Papers in refereed journals		226	46

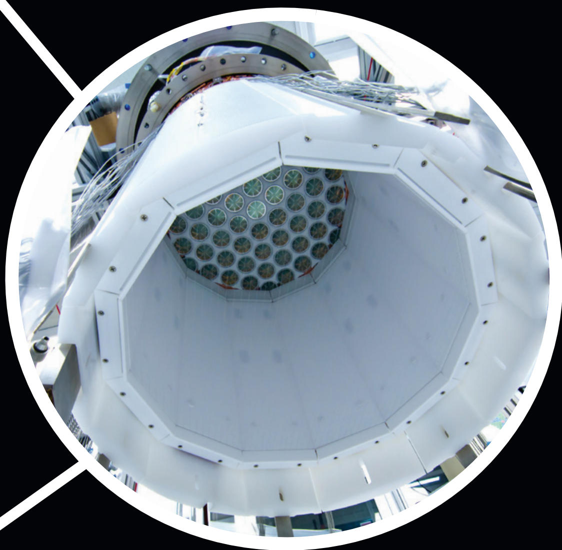
s	Detectors and Applications	Computing	**TOTAL**
	0	2	**6**
	1	2	**6**
	4	1	**15**
	2	3	**24**
	1	12	**49**
	52	50	**274**
	19	7	**293**

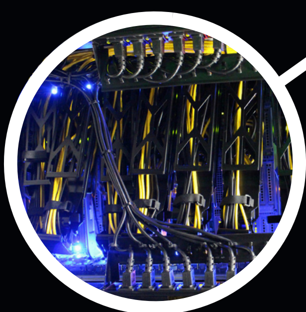
Astroparticle Physics
Particle Physics
Detectors and Applications
Computing



Experimental particle and **astroparticle physics**

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





Computing

research at

LIP

Experimental particle and astroparticle physics

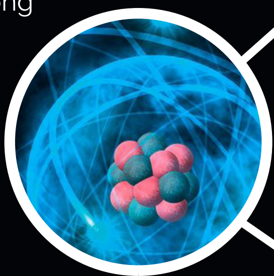
Development of new instruments and methods

LHC experiments and phenomenology

- ATLAS
- CMS
- Pheno

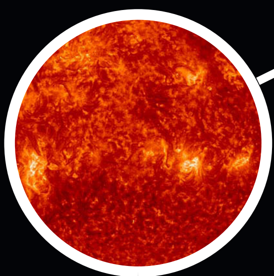
Structure of matter

- pQCD
- HADES
- NUC-RIA
- NPstrong



Cosmic rays

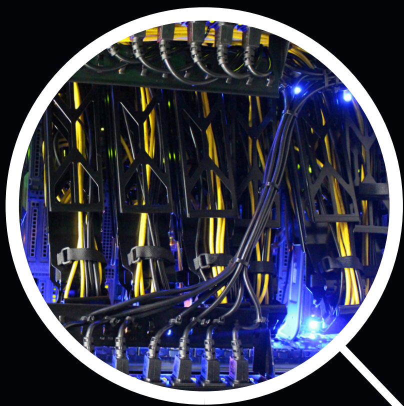
- AMS
- Auger
- SWGO / LATTES

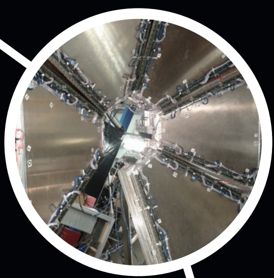


Dark matter and neutrinos

- DARK MATTER
- NEUTRINO
- SHiP

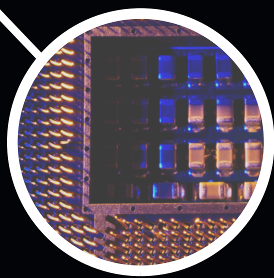
Computing





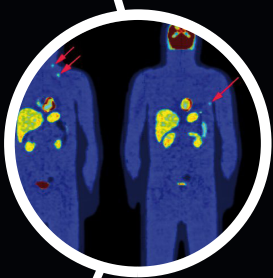
Detectors for **particle** and **nuclear physics**

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



Scientific computing

- GRID
- Advanced Computing
- SPAC



Health and **biomedical applications**

- RPC-PET
- Proton Therapy
- OR Imaging
- Dosimetry

Space applications

- Space Rad
- i-Astro

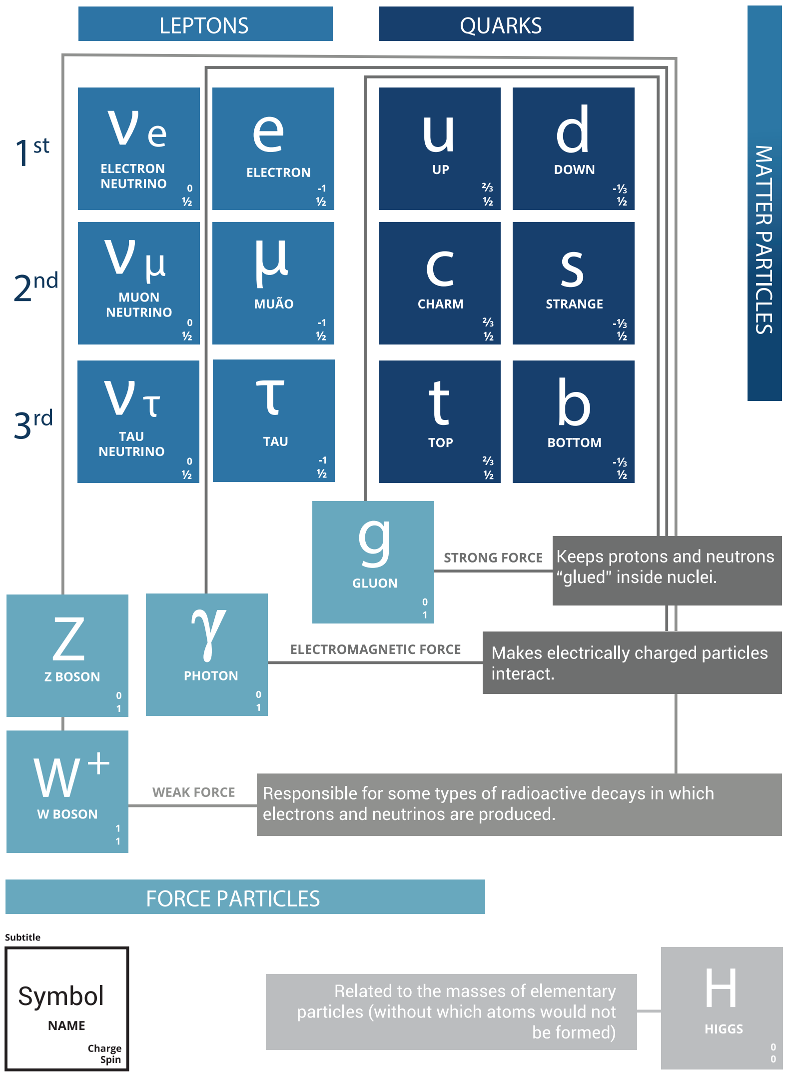
In a nutshell...

All matter we see around us is made of only three elementary particles: electron (e), up quark (u) and down quark (d). These particles are pieces of a larger puzzle, the Standard Model of Particle Physics (SM).

In the SM there are three families of elementary matter particles, successively heavier and with shorter lifetimes. In each family there is also a neutrino. Neutrinos are very light, weakly interacting particles which arrive, for example, from the Sun.

Particles interact with each other through forces, which in fact result from the exchange of other particles (called force particles) between them.

For each type of matter particle there is a matter anti-particle, which is exactly the same but with opposite charges.



The Standard Model is one of the most successful theories in the history of physics.

Still, it leaves many unanswered questions:

- Why three families of particles?
- What happened to all the anti-matter created in the big bang?
- How to include gravity in the theory?
- What is dark matter, which we know is 5/6 of all matter in the Universe?

At LIP we seek to answer these and other questions about our Universe!

To do that, we accelerate and collide particles at high energies, creating new particles (E = mc²). We also study particles that come from outer space, bringing information about the history and composition of the Universe.

To "see" particles we develop and operate detectors that can register the passage of particles and measure some of their properties. Particle detectors can be rather complex devices. Particle physics technologies are useful for other purposes too.

Experimental particle & astroparticle physics

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

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 the ways in which 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 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 newly approved AMBER experiment; 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 brings remarkable theoretical consistency to this research line, as well as opportunities for collaborations between different groups.

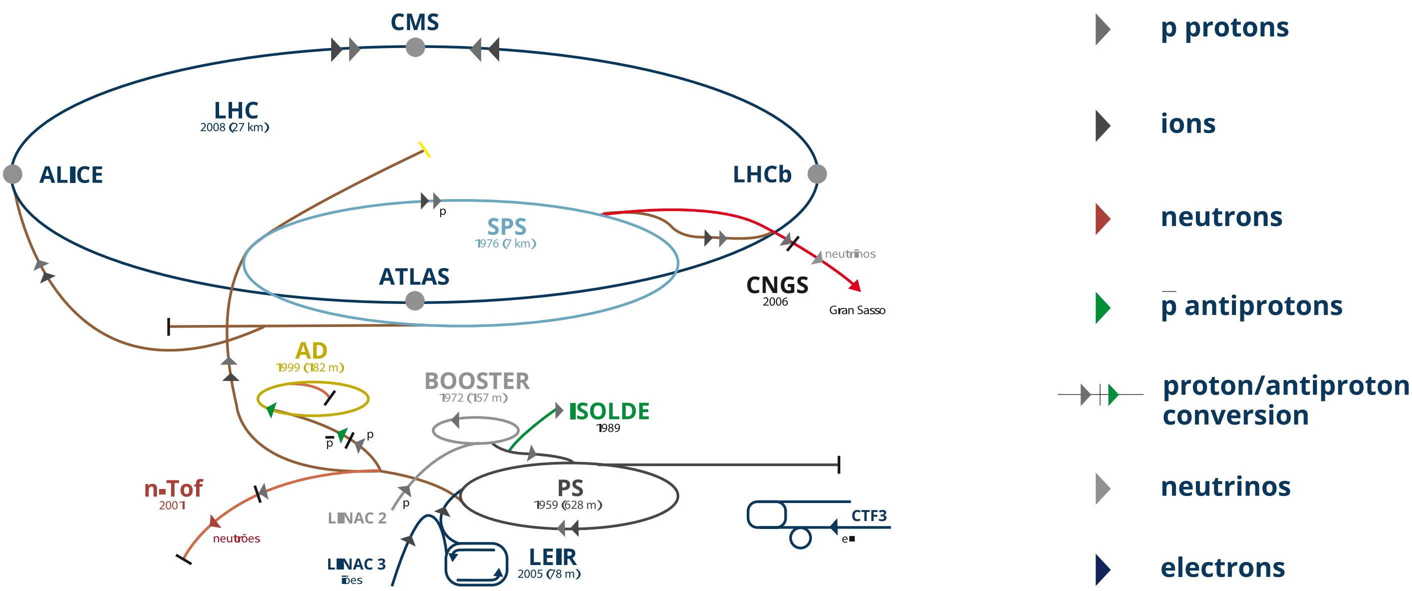
Experimental particle physics is conducted in ever more powerful accelerators, but also in astroparticle physics experiments, detecting particles that come to us from the cosmos. The quest for dark matter, a deeper understanding of the elusive neutrinos, or the origin and nature of charged and neutral 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.

More recently embraced projects are the participation in DUNE, one of the two flagship neutrino experiments for the next decade; the SWGO project for the installation of a wide field-of-view gamma ray observatory in the Southern hemisphere; and SHiP, an experiment proposed to be installed in a beam dump facility at the SPS to search for hidden sector particles.

LHC experiments and phenomenology

Physics at the energy frontier

With the LHC Run 2 (2015-2018) completed and the upcoming Run 3 starting in 2022, the year 2020 was used to continue analysing the accumulated data set and to prepare for the future (unexpectedly, also to deal with the COVID-19 pandemic). The ATLAS and CMS groups at LIP have been deeply involved in the exploration of the unique LHC data, as well as in detector upgrades. The Portuguese participation in the LHC Phase 2 upgrade was confirmed by a Memorandum of Understanding signed by the Portuguese funding agency FCT in 2019 and both teams have ramped up their work on this challenging project. The new sub-detectors and upgrades will be installed during the long shutdown from 2025 to 2027, and the High-Luminosity LHC (HL-LHC) commissioning will start at the end of 2027. The vastly enhanced accelerator and detector capabilities will guarantee optimal physics exploitation. During 2020 the LIP Phenomenology group has 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.



LIP at the LHC

Research at CERN's Large Hadron Collider (LHC) is central to the quest for the fundamental physics laws of Nature. LIP is member of the ATLAS and CMS collaborations at the LHC since their creation in 1992 and had a leading role in the design and construction of important components of the detectors: the data acquisition system of the CMS ECAL sub-detector, used to measure the energy of electrons and photons; the ATLAS TileCal sub-detector, used to measure the energy of hadrons, and the trigger systems that performs the online selection of the interesting collisions in each of the experiments. After the LHC start-up in 2010 LIP made major contributions to the physics program of both ATLAS and CMS. Both groups were involved in the discovery of the Higgs bosons, and are now measuring its properties. LIP is also involved in top quark physics, B mesons and QCD studies, heavy ion collisions and a wide spectrum of searches for hints of particles or phenomena beyond the Standard Model of particle physics.

Precision measurements: Higgs boson and top quark

In 2018 ATLAS and CMS have both observed the long-awaited interactions of the Higgs boson with the heaviest quarks: b and top. Since 2019 the ATLAS team is focusing on the accurate measurement of the Higgs boson properties, namely 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 (VH, V=Z,W) and with a top-quark pair (ttH). The first measurement of the high transverse momentum cross section of the H–›bb decay in VH production was completed and published in August 2020. The analysis of ttH with H–›bb decay with full Run 2 data is expected soon. Any deviations from the expectations of the SM of particle physics may have far-reaching implications including the possibility of helping to explain why the Universe is composed of matter largely dominating over antimatter. Getting enough sensitivity to reach clear conclusions will be a long and challenging process. 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. This has been the subject of a PhD thesis defended in 2020. Observing Higgs pair production is a very challenging goal, which may only be achieved at the end of HL-LHC. The experimental work has been complemented by studies of the Phenomenology group on the reach of experimental analyses at the HL-LHC and a possible Future Circular Collider.

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 had a leading role in the data analysis and preparation of the first publication of Run 2 results on the measurement of the top-quark pair production cross section with the top quark decaying to tau leptons. The analysis has been published in 2020, and the subject of a PhD thesis in the group. Studies of lepton flavor universality in the same final state are ongoing. The group is also pursuing a search for top-quark 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 precision 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.

Searching everywhere

LHC experiments are searching everywhere and in every way for hints of particles or phenomena beyond the SM of particle physics. This includes looking for tiny deviations in precision measurements, searching for new particles or phenomena predicted in proposed theories and models, and performing wide searches employing powerful analysis methods to search for any kind of anomalies in data. The ATLAS team developed a strong expertise in direct searches for new phenomena. Run 2 search analyses are at the final stage for example in the search for the production of exotic heavy quarks, whose existence would account for the unexpectedly low value of the Higgs mass. To separate the small signal from an overwhelming background, they exploit striking final state topologies (for example with energetic leptons) and use deep-learning techniques.

LHC experiments are actively searching for a particle capable of explaining the mysterious dark matter, which is known to exist through its gravitational interaction. Missing energy in the events is a signature for particles escaping detection and may also indicate the presence of a dark matter particle. In 2020 the ATLAS team lead the search for monotop event using the full Run 2 dataset. The CMS team on the other hand has focused on the search for dark matter produced in association with a Higgs boson decaying to a final state with four leptons. The search is developed with the full Run 2 data set. Supersymmetry, according to which each known particle is expected to have a supersymmetric partner (sparticle) with different spin, could include the perfect candidate to explain dark matter. However showing that this is realized in Nature has so far proved a difficult task. In 2020 the CMS team performed a search for the lightest scalar top (stop) in the Run 2 data using an multi-variate analysis approach.

The Force is Strong

The study of rare decays with CMS data has remained a priority. The interest is reinforced by the large accumulated datasets and in particular by the so-called flavor anomalies, consisting of different hints of deviation of SM's expected flavour universality. The group is keeping its focus on $b \rightarrow sll$ transitions, at the core of the flavor anomalies, and has carried out measurements of b-quark production and fragmentation, a crucial ingredient for the measurement of rare B decays, esp. $B \rightarrow \mu\mu$. Another important decay realizing the $b \rightarrow sll$ transition is $B \rightarrow K^*\mu\mu$. This is particularly pressing in view of reported departures from SM predictions that centrally contribute to the flavor anomaly puzzle.

The group is carrying out the analyses with the full Run2 data. 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 c states, now published.

ESPPU

In June 2020 the CERN Council approved the European Strategy for Particle Physics Update. This document is the product of more than a year of reflection and debate by the whole community, and defines the global priorities in this field for years to come.

The LHC and Pheno groups at LIP were deeply involved in studies that informed this strategy. While the next steps at the LHC are the first priority, the document envisages a two-step strategy, with a "Higgs factory" (an e+e- collider) followed by a huge hadron collider (the Future Circular Collider) that could be built in the CERN region.

Ana Luísa Carvalho received the prestigious **ATLAS PhD Grant.**

Tahereh Niknejad and Ksenia Shchelina were awarded CMS prizes for outstanding contributions.

The Hot Universe

The LHC provides unique opportunities to study heavy-ion collisions and observe the Quark Gluon Plasma (QGP), which existed in the hot and dense medium of the very early Universe. The ATLAS and CMS groups are exploring the characteristics of QGP using different probes, both based on the behaviour of the heavy b quark as it crosses the plasma. ATLAS focuses on the use of hadronic jets initiated by heavy quarks, and has been developing b-tagging algorithms adapted to this difficult environment. In 2020, b-trigger performance studies in PbPb collisions were completed.

The CMS team has concentrated on the identification and measurement of b-quark hadrons, bringing unique expertise of B physics into the heavy ion realm. The group has been playing a central part in the investigation of first B meson signals in PbPb data. The analysis of the PbPb 2015 data was released. This work is very well matched to the expertise in the Phenomenology group. Among other aspects, they studied in detail the kinematics of parton splitting in the medium.

Bridging theory and experiment

LIP's Phenomenology group conducts research bridging theory and experiment in particle and astroparticle physics. Its research, while independent, is centred around areas in which LIP has active experimental activities and aims to identify areas in which LIP's broader programme may evolve in the future. Its purpose is to strengthen the impact of the overall LIP programme through the provision of excellent directed phenomenological research.

Since its creation in 2018, the group has steadily grown in size and in the breadth of its research programme. The core group portfolio of activities includes top physics, Higgs, quarkonia, QCD precision physics, heavy-ions, and BSM physics. In 2020 synergies with LIP's Simulation and Big Data competence centre continued to deliver significative results: two works were submitted and accepted for publication, and the project to distinguish jets modified by their propagation in a QGP and their vacuum counterparts using image processing techniques will soon be submitted for publication. For the future, they will explore possible synergies with the cosmic ray experimental groups and with the strong interaction group NPstrong that joined LIP last year. Group members lead the work package on jet studies in the European Consortium STRONG2020.

Tools of the trade - Detector Upgrades

During 2020, the ATLAS and CMS teams at LIP have worked on their experimental tools and ramped up activities in the upgrade of each detector. Also, both teams contribute to the LHC Grid computing maintenance and operations.

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. The LIP CMS group continued R&D 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. Prototype readout units have been designed, fabricated, and tested. The team has also continued the development of the new electromagnetic calorimeter readout system.

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 replace the current electromagnetic calorimeter endcaps. Machine-learning algorithms to discriminate pileup background using this detector have also been developed.

The ATLAS team coordinates the maintenance, operation and calibration of the TileCal calorimeter, and is deeply involved in the upgrade of the TileCal and of the Trigger and Data Acquisition (TDAQ). LIP has full responsibility for the new TileCal high voltage distribution, to be produced mainly in Portuguese industry. Sensitive electronics components will be placed in a service cavern and power distribution will be through thin cables to the front end, thus allowing much greater accessibility for maintenance. The team has designed, produced, and tested prototypes of different types of electronics boards in collaboration with LIP's e-CRLab. Within ATLAS TDAQ, the group is contributing to the Hardware Track Trigger. LIP is responsible for most of the production of a communications board and takes part in software development and performance studies. The team is also involved in R&D for the use of hardware accelerators (GPU) in the trigger system.

// CONTACTS

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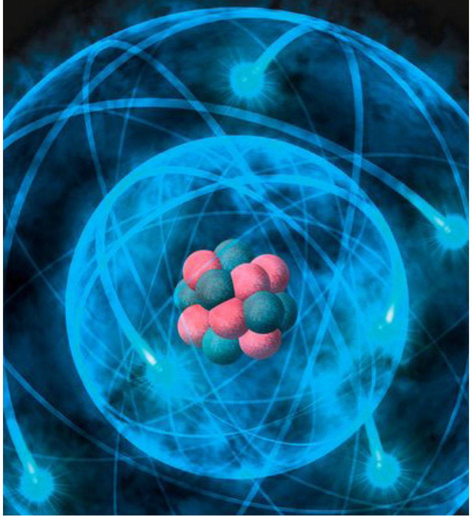
Michele Gallinaro (CMS), michgall@cern.ch
Guilherme Milhano (Pheno), gmilhano@lip.pt



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 PQCD, Partons and QCD group is currently involved in the COMPASS experiment at CERN, as well as in the preparation of the newly approved AMBER; FAIR (Facility for Antiproton and Ion Research) will be the new step at GSI and LIP is part of the HADES and R3B experiments. NPstrong, Nuclear Physics and Strong Interactions group brings remarkable theoretical consistency to this research line, as well as opportunities for collaborations between different groups.

The workings of nucleons

The LIP PQCD group is heir to a long tradition in CERN's fixed target experimental programme, starting in the 1980s with the heavy ion experiments NA38 and later NA50. The group now concentrates on the COMPASS experiment and in the preparation of the future AMBER experiment.

Major aims of COMPASS are to discover how quarks and gluons contribute to the spin of the proton and to investigate the variety of particles that quarks and gluons can form. To do so, they collide high intensity muon or hadron beams with a polarized target (made out of e.g. hydrogen or deuterium) 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 that observes the particles resulting 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 phase devoted to understanding the tridimensional nucleon structure started in 2012. COMPASS enters its last data taking campaign in 2021/2022, with a unique deep inelastic scattering (DIS) measurement of a muon beam off a transversely polarised deuteron target. This shall lead to an accurate determination of the spin dependent transverse momentum distribution of the d-quark in the nucleon.

The LIP group is responsibility for the COMPASS detector control system (DCS). The long shutdown at CERN during 2019/2020 offered the opportunity to prepare the system for the last data taking. This was possible in spite of the COVID-19 pandemic as the COMPASS DCS coordinator, Christophe Pires, was one of the few hundred people with access to the CERN site even during lockdown periods.

In late 2020 the so-called COMPASS "dry run" was successfully conducted: all systems were tested without a particle beam in the experiment, with the presence of the DCS coordinator and remote shifts done by other members of the group.

The LIP group has always been deeply involved in the analysis of the COMPASS data. In 2020 a paper on the measurement of the kaon and proton multiplicity ratio from deuteron target in DIS was published. Other analyses are still ongoing.

Last but not least, the AMBER experiment phase-I proposal was approved by the CERN research board in December 2020. AMBER will address fundamental QCD topics such as the origin of the mass of hadrons. The LIP group and in particular its principal investigator (PI) Catarina Quintans is one of main proponents.

Stars and Nuclei

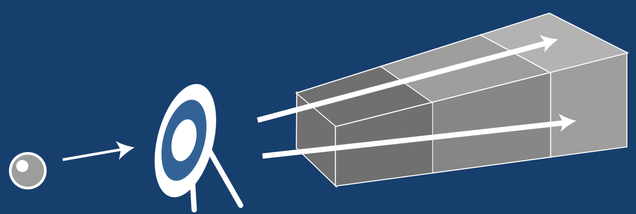
The GSI Helmholtz Centre for Heavy Ion Research in Darmstadt (Germany) operates the only facility allowing to accelerate nuclei of all chemical elements occurring on Earth. The facility has been closed for a few years and is slowly coming back to life. The performed upgrades will allow to put into operation the SIS100 1.1 km ring accelerator, the key component of the new Facility for Antiproton and Ion Research (FAIR) currently under construction. At FAIR scientists will produce matter under extreme conditions (of pressure, density, temperature) such as those existing in giant planets, stars, or during stellar explosions and collisions.

Stars and stellar explosions create the chemical elements everything is made of. To understand the stars, we first need to understand atomic nuclei. This is the goal of NUSTAR (Nuclear Structure, Astrophysics and Reactions), one of the four research pillars of FAIR: it will use the unprecedented range of radioactive ion beams, with all kinds of exotic isotopes, to study the complex stellar nuclear reaction chains. LIP's Nuclear Astrophysics Group (NUC-RIA) is part of the NUSTAR R3B experiment (Reactions with Relativistic Radioactive Beams).

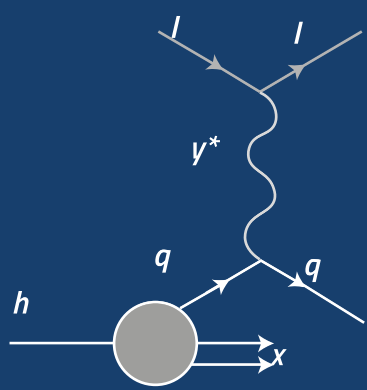
Another pillar of FAIR is CBM (Compressed Baryonic Matter). The collision of atomic nuclei at high speeds can reproduce for a split second the conditions inside supermassive objects such as neutron stars. This is were sits the HADES experiment, in which LIP is involved. Scientists want to find out how matter changes at such densities, for example, if all the matter breaks down into its elementary particles (quarks and gluons) to create a plasma like the one that existed shortly after the big bang. Both HADES and R3B are among the first experiments to start operation in the Phase-0 of FAIR.

The LIP group designed, built and operates an essencial component of the HADES spectrometer, the so-called RPC-TOF-W: a wall (W) of 3 m x 3 m of resistive plate chambers (RPCs) that accurately measures the crossing time of particles (TOF, time-of-flight). This is important information for the determination of the type and momentum of particles. In 2020 the LIP group worked to prepare HADES for FAIR: upgrading the RPC-TOF-W to handle the expected high particle rate (200 kHz) and completing the design, construction and installation of the two modules of the RPC-TOF-FD, which extends the TOF measurement capabilities to the forward region of the detector (FD, closer to the beam direction). The foreseen beam test was postponed to 2021 due to the pandemic.

As for the NUC-RIA group, experiments planned to be conducted in several labs in Europe have been canceled, but the diversity of the group's activities helped to make 2020 a productive year. The possibility of using a large area RPC in the R3B experiment was explored in collaboration with the HADES group. The device should be transported to GSI in 2021 and used in the 2022 run. Teamwork with RPC experts at LIP is ongoing also in the study of exotic neutron-rich nuclei. An RPC-based device to detect the high-energy neutrons emitted by some of these nuclei has been designed and will be prototyped in 2021. Last but not least, a new research line in nuclear astrophysics was initiated with measurements of low energy proton reaction cross-sections (which measure how likely reactions are to happen) that are relevant for astrophysics. The experiments were performed at CTN/IST.



Fixed-target experiment



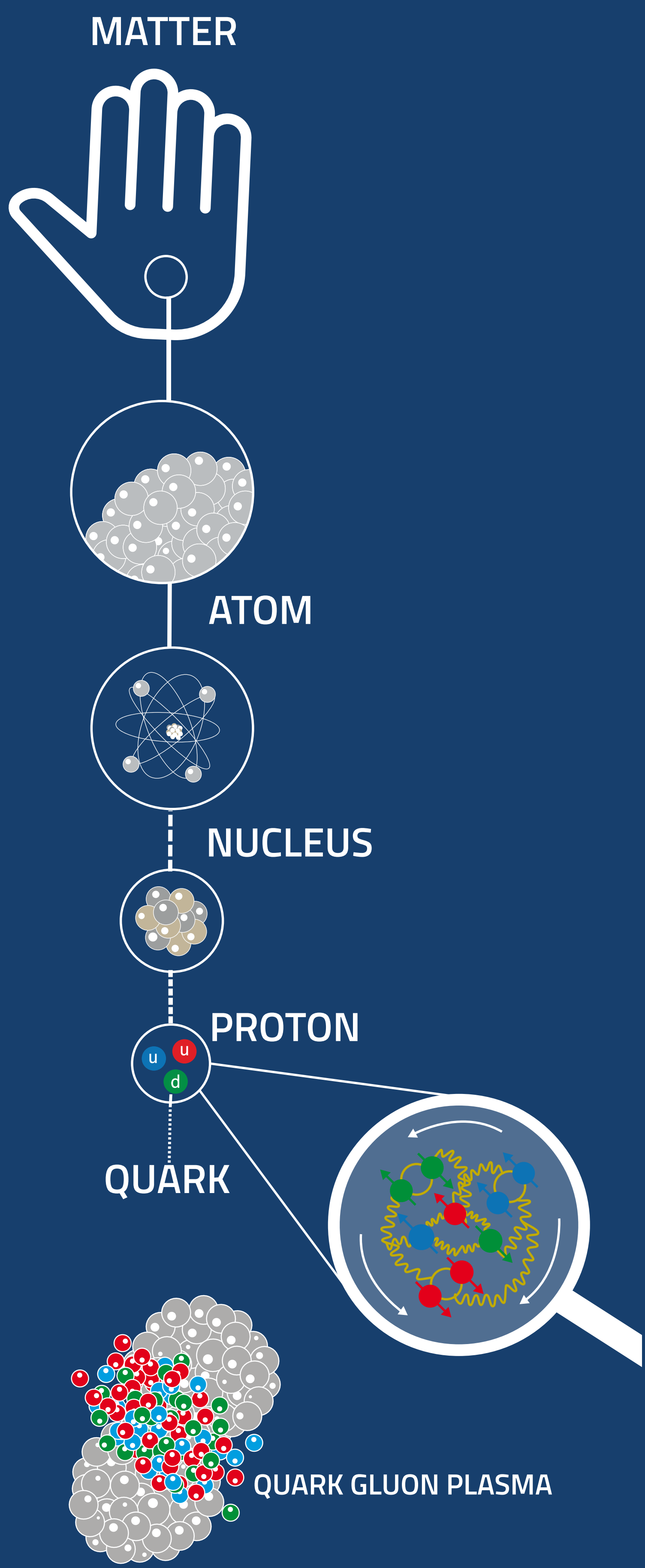
Deep inelastic scattering probes the insides of hadrons using electrons, muons and neutrinos. It provided the first convincing evidence of quarks. The higher the energy, the finer the resolution on the components of the nucleus.

Jumping into theory

NPstrong, the Nuclear Physics and strong Interaction group, joined LIP in early 2020. Its members share research interests in nuclear and hadron physics. The group works on a variety of topics in QCD with computational methods in order to make predictions on measurable quantities, namely hadron properties. The fundamental questions behind these activities are the origin of confinement of quarks in hadrons and in nuclei (the strong interaction binds quarks and gluons in hadrons but also protons and neutrons in nuclei), the origin of the mass of hadrons, and the properties of matter in extreme conditions such as heavy-ion collisions and neutron stars.

Astrophysical data reinforce interdisciplinary links between astroparticle, nuclear and particle physics; the NPstrong expertise at LIP is ideal for synergies. In fact, NPstrong naturally connects with the other groups in the Structure of Matter research line and with the Pheno group and can create new synergies.

Some of the highlights of 2020 explored the group's unique expertise on functional methods to discriminate between different models that describe exotic hadrons — hadrons that do not fit into the quark model due to their quantum numbers. According to the quark model, mesons are made of a quark–antiquark pair and baryons are made of three quarks. While the quark model can be derived from QCD, the structure of hadrons is more complicated than this model allows. The full quantum mechanical description of any hadron must include, besides the dominant (valence) quarks, a "sea" of underlying quark pairs and gluons, and allows for a variety of mixings. Thus there may be hadrons which lie outside the quark model. Among these are glueballs, hybrids (with valence quarks and gluons) and exotic hadrons such as tetraquarks or pentaquarks. In particular, the group studied the recently discovered LHCb pentaquark states, and four-quark candidates with light and heavy quarks such as X(3872), an exotic meson first observed by the Belle experiment in 2003 and whose quantum numbers have been determined by LHCb. The goal is to work towards the calculation of a wide range of hadron properties from first principles without any parameters.



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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 (electrons, protons atomic nuclei) 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 at the highest energies. LIP is committed to the Alpha Magnetic Spectrometer, the Pierre Auger Observatory, and the SWGO project for the installation of a wide field-of-view gamma ray observatory in the Southern hemisphere.

A unique particle detector in space

Since 1998 LIP is part of the international collaboration that designed and operates the Alpha Magnetic Spectrometer (AMS). AMS had two phases: the AMS-I 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 over 45 million events per day. AMS remains a unique observatory in space and is expected to continue taking data up to at least 2024.

AMS catches cosmic ray particles directly, before they interact in Earth's atmosphere. The detector is rather complex. It has different sub-detector layers that measure different particle properties, and a magnetic field causing particles to bend according to the sign of their electric charge. With its powerful particle identification capabilities, AMS allows to study in detail the fluxes of different types of cosmic particles, but also to search for antimatter nuclei and dark matter in the Universe.

LIP had an important role in the design and construction of AMS's Ring Imaging Cherenkov sub-detector (RICH). RICH detectors allow to identify charged particle types through the detection of Cherenkov radiation, emitted when a particle crosses medium with a velocity above the velocity of light in that medium. Identification is achieved by measuring the emission angle of Cherenkov radiation, which is related to the particle velocity. If the particle momentum is measured by another sub-detector, the particle mass can thus be obtained.

The LIP group still holds responsibilities in the RICH operations and monitoring, carried out 24h/24h from the Payload Operations and Control Center at CERN, and also in the algorithms used to reconstruct the properties of the detected particles from the raw data recorded by the RICH.

The magnetic activity of the Sun varies in 11-year cycles, affecting cosmic ray fluxes arriving to Earth in a way that depends on the particle charge. The north-south magnetic field component of the Sun also flips every 11 years at the minimum between two cycles. AMS observed the 24th solar cycle almost from the beginning, through the reversal of the magnetic dipole in 2013, and will continue operating at least until the magnetic reversal of the 25th cycle in 2023, observing the phenomenon with unprecedented detail. The LIP group is involved in the study of solar modulation effects, their interpretation under solar modulation models, and the study of associated propagation mechanisms.

Observations of isotopes of the same nuclear species provide information on galactic matter distribution and cosmic-ray propagation, taking advantage of the change in velocity and interaction probability for the same charge. The RICH, with mass separation capabilities beyond any other detector in space, is a key element in such studies. The LIP group started from the lightest case, proton/deuteron separation, and will proceed with isotope flux analyses in collaboration with other AMS groups.

The most energetic particles in the Universe

While at low and moderate energy cosmic rays are quite abundant, the flux decreases steeply as we go up in energy. The highest energy cosmic rays ever detected have energies of a few times 10^{20} eV. This corresponds to a macroscopic energy of tens of Joules, and is well above the energy available at any human-made accelerator. In addition, several open questions remain on the nature and origin of such particles. The highest energy cosmic rays are thus both messengers from the most energetic phenomena in the Universe and a window to particle interactions at energies above accelerators.

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, telescopes detect the ultraviolet light emitted by the showers.

The observatory will continue operations until 2025 and is currently completing an upgrade 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. Muons play a big role in unveiling the nature of the highest energy cosmic rays, as they may come directly from the first few, high-energy interactions. They are indirectly accessible in AugerPrime, and the development of powerful methods to separate them from the dominant electromagnetic signals is of the utmost importance.

MARTA is a joint Portugal-Brazil R&D project to directly measure the muon content of cosmic showers using low gas flux RPC installed beneath a small set of Auger ground detectors. MARTA activities were severely impacted by the COVID-19 pandemics. Travel restrictions and strict confinement in Argentina made it impossible to complete the first unit's commissioning and substantially impacted fieldwork even by the Observatory staff. Also the production of the final modules in Brazil was delayed. In Lisbon it was possible to proceed with the testing of the electronics and with the development of the MARTA simulation and reconstruction software, which is now deployed with the Auger software packages.

In parallel the LIP group is thoroughly exploring the Auger data. The team holds great expertise in shower physics. Previous work on model development and innovative analysis methods will allow for a central contribution to the analysis of AugerPrime data. The study of the shower properties had significant developments in 2020. Ongoing work on the relation of the first interaction with the characteristics of the shower, in particular its muon component, has been successfully completed and is being prepared for publication.

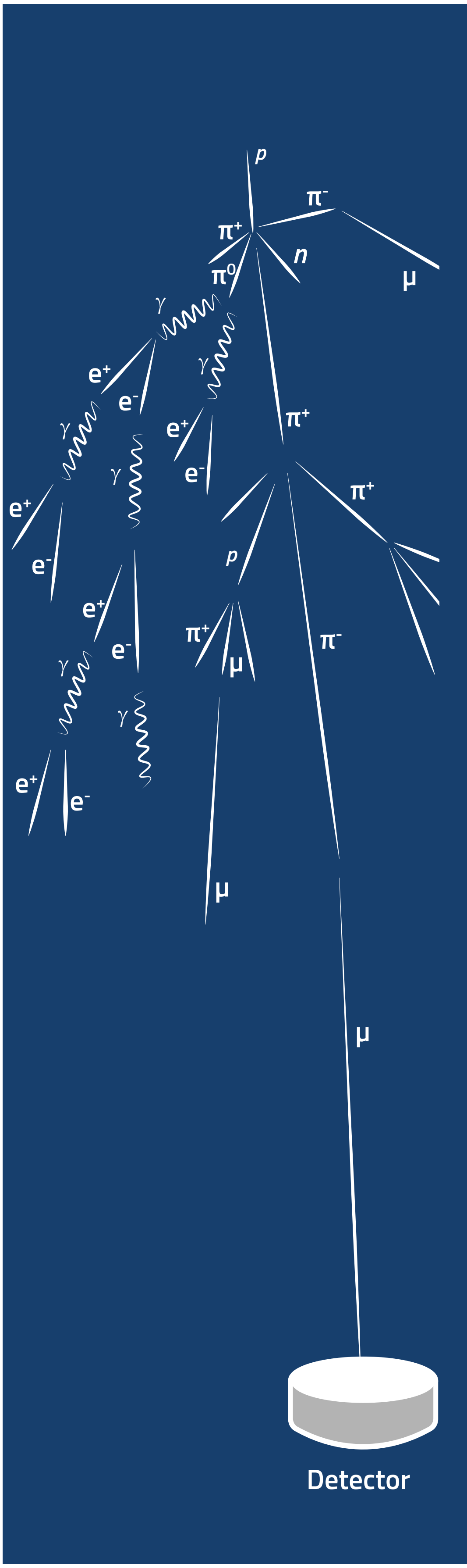
At the top of mountains

High-energy gamma rays provide an excellent window to the most extreme phenomena in the universe. They are not deflected by magnetic fields, thus pointing to their sources, and they probe supernovae, black holes in active galactic nuclei (AGN) and the origin of gamma-ray bursts (GRB). Gamma-ray emission is associated to charged cosmic-ray acceleration, the production of cosmogenic neutrinos and gravitational waves. Gamma-ray astrophysics could also provide indirect hints of dark matter. The observations of gamma-ray telescopes in the last decade changed radically our perception of the Universe. High-intensity flares with an energy spectrum extending beyond the GeV have been observed.

Direct detection of primary gamma-rays is only possible with satellite-based detectors. However, the cost of space technology limits their size, and thus their sensitivity at higher energies. In the atmosphere, gammas interact creating a shower of particles. These showers can be studied in imaging atmospheric Cherenkov telescopes, highly sensitive pointing instruments (such as CTA) or in high altitude air shower arrays, These have a wide field-of-view and are ideal to search for transient sources.

The Southern Wide-field Gamma-ray Observatory (SWGO) collaboration was formed in 2019 after a workshop held in Lisbon where different groups developing similar projects decided to joint efforts. Today, SWGO comprises 52 research institutions from 12 countries. The main goal of SWGO is to pave the way for the construction of the next wide field-of-view gamma-ray observatory to be installed at high altitude (4500 m) in South America. The new observatory will cover an extended energy range and address a rich science program. Moreover, SWGO will be the only wide-field observatory surveying the Southern sky and thus the centre of the galaxy region. The SWGO collaboration will produce by 2023 a complete proposal for the new observatory.

The Portuguese participation in SWGO is focused on specific goals spanning many different areas: from the definition of the science requirements to the detector design, from the development of new analysis methods to the design of innovative calibration systems. Some of the 2020 highlights were the assessment of SWGO's potential to detect transients at low energies (sub-TeV); investigation of new trigger strategies to lower the energy threshold of the experiment; development of a new calibration concept based on RPC able to operate at high altitude. In collaboration with CBPF (Rio de Janeiro), University of Granada and University of Coimbra the LIP group is developing methods to determine the shower energy and core position, as well as machine learning based algorithms to distinguish showers initiated by gammas from showers initiated by charged cosmic rays. LIP also contributed to the detector and array concept design and to the simulation framework.



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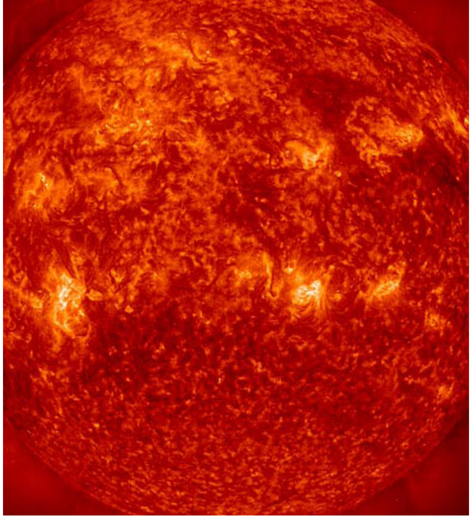


Dark matter and neutrinos

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 (Canada), the LZ dark matter detector at the SURF Laboratory (USA), and the more recently embraced participations in DUNE, one of the two leading neutrino physics experiment of the next decade, in SHiP, proposed for CERN's SPS (Super Proton Synchrotron) and in R&D for third generation dark matter search experiments.

Searching for the dark side

Although we cannot see dark matter, we can see the effects of its gravitational interaction. According to the most recent experimental evidence, dark matter makes up 27% of the Universe, and we have strong clues that dark matter is made of particles that interact very weakly. One of the ways to search for dark matter is to use super-sensitive underground detectors to identify very rare interactions between dark matter particles crossing the Earth and normal matter nuclei in our detector.

The LIP Dark Matter group is a founding member of the LUX-ZEPLIN (LZ) experiment at the Sanford Underground Research Facility (SURF). The LZ detector utilizes 7 tonnes of liquid xenon as active medium in a dual phase TPC to search for potential dark matter signals. The interaction of a dark matter particle with a xenon nucleus would cause a nuclear recoil and produce a detectable photon signal. A TPC is a detector able to measure the 3D position of each spot where an interaction occurred.

LZ has been designed to improve on the sensitivity of the prior generation of experiments by a factor 50 or more. All efforts were made to improve rejection of unwanted background events, namely from cosmic rays and natural radioactivity. In particular, the detector is placed 1480 m underground; there are auxiliary veto detectors, including a liquid scintillator outer detector; the detector is inside a double vessel of radio-pure titanium. Due to its extremely low background, LZ can also be used for other studies such as the search for Xe rare and forbidden decay modes.

The LZ first run, expected to start in late 2020, has been delayed due to the COVID-19 pandemic, which caused delays of several months in the assembly, integration, and commissioning of the detector.

In 2020 the LIP group contributed to the preparation for commissioning of the Control System (CS) and online Data Quality Manager (DQM), the two elements of the experiment infrastructure under LIP's responsibility. The group also developed tools for data analysis and background simulation, as well as determinations of the sensitivity of LZ to Xe rare decays.

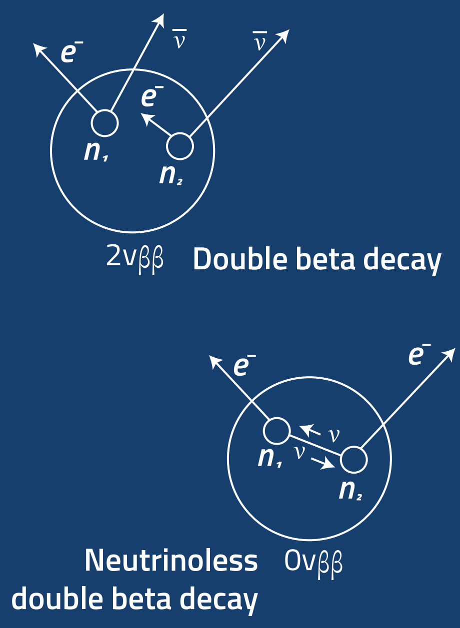
The search for the neutrinoless double beta decay ($0\nu2\beta$) of ^{136}Xe is the second most important goal of LZ, and the LIP group has a leading role in this analysis. In 2020 the work on the LZ sensitivity to this process was completed, the corresponding paper was published, and a PhD thesis having this analysis as main topic was submitted. Sensitivity studies for the ^{134}Xe rare decays have been carried out and one more paper was published.

Finally, the group was involved in R&D projects for the preparation of a next generation dark matter direct search detector.

SnowMass 2021

Snowmass is organized by the Division of Particles and Fields of the American Physical Society and provides an opportunity for the entire particle physics community to come together to identify and document a scientific vision for the future of particle physics in the U.S. and its international partners. The scientific input from Snowmass is used as input to develop a strategic plan for particle physics that can be executed over a 10 year timescale, in the context of a 20-year global vision for the field.

In 2020, both the Dark Matter and the Neutrino Physics LIP groups were active in the Snowmass process. Alexandre Lindote, from the Dark Matter group, is one of the two main authors of a letter of intent. The Neutrino group is part of three proposals.



Understanding the elusive neutrinos

Neutrinos are the second most abundant particle in the Universe, after photons. They are constantly being produced in nuclear reactions inside stars. On Earth, radioactive decays and cosmic rays interactions in the atmosphere also produce neutrinos. Neutrinos interact only weakly with matter and are thus extremely hard to detect. They can go through the Sun and the Earth undisturbed, bringing important information about the Universe. There are three neutrino types, or flavours: electron, muon and tau neutrino. Neutrinos alternate between the three flavors while propagating — we say they oscillate. For that, neutrinos must have a non-zero (although tiny, and as yet unknown) mass, which was not foreseen in the Standard Model of particle physics. Another open question about neutrinos is whether they are Majorana particles, i.e., if they are their own antiparticle. The discovery of neutrino oscillations gave the 2015 Nobel Prize to Takaaki Kajita, from the Super-Kamiokande experiment, and Arthur B. McDonald, from the SNO experiment.

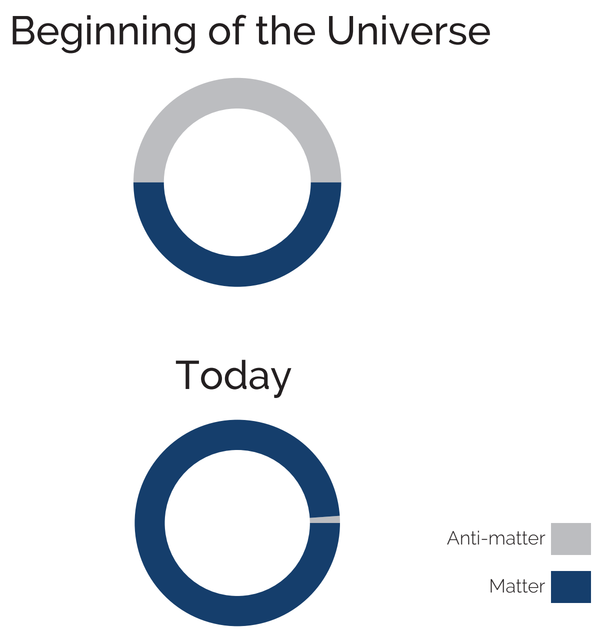
SNO+

The LIP Neutrino physics group joined the SNO experiment in 2005, and is a founding member of the SNO+ international collaboration. The detector is located 2 km deep underground, at SNOLAB (Canada). An acrylic sphere with 12 m diameter and 6 cm thickness is surrounded by 9500 light sensors. The SNO+ experiment followed from SNO, replacing the active medium inside the sphere: from heavy water to water and then to liquid scintillator. The main goal of the experiment is the search for neutrinoless 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.

The LIP group has participated in the construction of calibration systems and is currently very active in the analysis of the data from water and partial scintillator fill phases, with leadership or strong contributions to background studies, antineutrino analyses and calibrations. As highlights, the group published a measurement of the neutron-proton capture cross section in water; and the detector response in energy is now understood to better than 1% as a result of a new optical calibration completed by the LIP group in early 2020. Those developments, coupled with a background reduction due to better shielding, will improve the precision in a number of ongoing physics analyses. The scintillator fill will be completed in mid-2021, with Tellurium loading expected later next year.

DUNE

DUNE is a long baseline experiment: neutrino and anti-neutrino beams will be produced at Fermilab and detected 1300 km away at SURF, in large Liquid Argon (LAr) TPCs (the far detector). Beam is expected in 2026, and the first detector installation in 2025. DUNE will certainly be one of the great projects of the next decades, studying in particular the mass hierarchy of neutrinos and investigating wether neutrinos can contribute to explain the matter-antimatter asymmetry in the Universe.



The LIP Neutrino Physics group joined DUNE in 2018. Activities are focusing initially on the design of the far detector calibration systems and in the operation and data analysis of the ProtoDUNE prototypes. The first ProtoDUNE run at CERN was concluded in early 2020. The LIP group participated in the analysis of the ProtoDUNE dual-phase purity monitor data and in the maintenance of the ProtoDUNE single-phase trigger system, including the introduction of new triggers used in test runs with a neutron calibration source.

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. The main goal of SHiP is to explore the so-called Hidden Sector of particle physics, predicted in several proposed extensions of the Standard Model, in a region of phase space that is not accessible to the LHC experiments. The physics program of SHiP further encompasses a Standard Model precision measurement component, especially allowing for a unique study of the tau neutrino.

The LIP SHiP group has been created in 2018 and is involved in both detector development and analysis. Currently the group is responsible for the veto detector, and competing proponent for the timing detector, both based on RPC technology. Both detectors are crucial to ensure a nearly zero background environment for the experiment. The group is involved in selection optimization employing machine learning techniques for several analyses.

While the SHiP experiment is a longer-term project, shorter-term, associated projects are being actively investigated. These explore complementary locations at CERN, served with different beam energies and intensities. In particular, following favourable feedback by the LHC Experiments Committee (LHCC), the technical proposal for SND@LHC has been submitted. The SND (Scattering and Neutrino Detector) is one of the components of SHiP. Neutrinos are produced abundantly at colliders, still collider neutrinos are usualy not detected. The new detector could be installed in the LHC tunnel, away from the collision point and near the beam-line direction, with start of operations foreseen for Run 3 of the LHC next year.

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Development of new instruments & methods

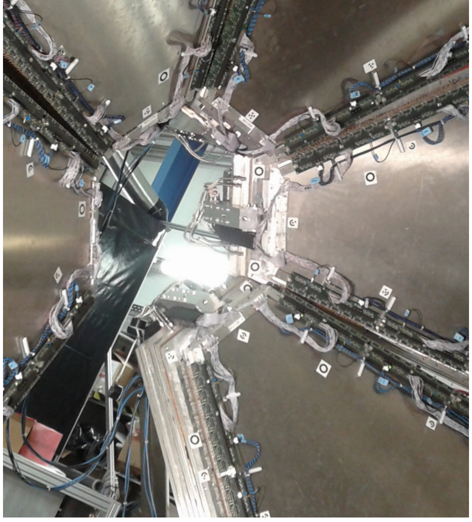
▪ Detectors for particle and nuclear physics ▪ Health and biomedical applications ▪ Space applications

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 also the associated data acquisition and readout electronic system, trigger and data processing tools, control systems and other ancillary systems.

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, 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 center for nuclear technology, several hospitals, medical research centers, and companies.

Space exploration is another 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 specialities include Resistive Plate Chambers (RPC), neutron detectors, gaseous and Xenon-based detectors, optical fibere calorimeters and fast electronics for data acquisition systems. Both applications to other fields and the preparation for future experiments open great opportunities for detector R&D.

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 heliumfree 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 directions.

RPC-PET: medical imaging

A priority for LIP is the development of RPC-based devices for medical imaging through Positron Emission Tomography (PET). The group is currently focused on the development of a human-brain PET device in collaboration with the company ICNAS Produção. For more details, please see the Health and Biomedical Applications research line.

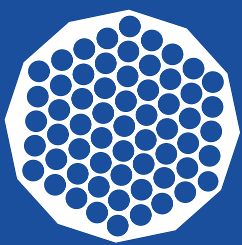
Time and position sensitive RPC

Many large particle physics experiment presently operating use RPC-based detectors: their very good time precision is ideal for trigger or timing, and they can (inexpensively) cover large areas.

Detectors at LIP

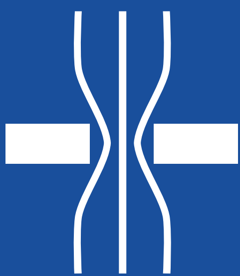
Resistive Plate Chambers (RPC)

Flexible and robust gas detectors with very good time and space resolution and a wide range of applications.



Liquid Xenon detectors

Very sensitive detectors in which dark matter particles would cause nuclei to recoil producing a light and charge signal

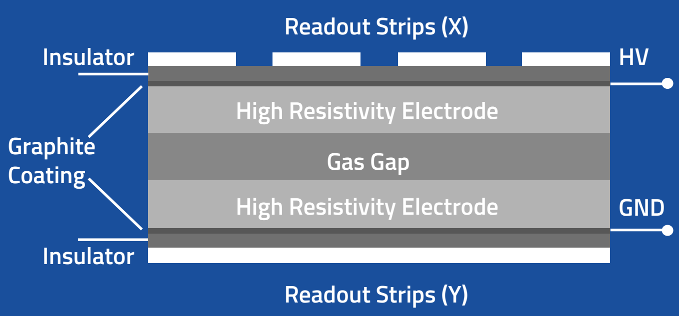


Patterned Gas Detectors (PDG)

In modern gas detectors, instead of wires one uses electrodes deposited in a electronics board.

The LIP RPC group develops and builds RPC detectors for particle and nuclear physics experiments using an innovative technology that allows to achieve 98% efficiency and 50 ps time precision in large area detectors (around 2 m²). Recently detectors for HADES at GSI and SHiP at CERN have been constructed.

As for position information, it depends essentially on the chosen configuration for the readout strips and data acquisition channels. The precise measurement of position in combination with time is of interest for particle identification, based on the measurement of the time-of-flight (TOF) of particles in more than one RPC plane.



Resistive Plate Chamber (RPC)

Resistive Plate Chambers are gaseous particle detector with two parallel electrode plates made of a high resistivity material (glass). The gap between them is filled with a gas mixture. As a charged particle travels through the detector, it will ionize the gas between the plates. High voltage applied to the plates creates a uniform electric field, and a localized electron avalanche is instantaneously produced directly on the particle's trajectory and drifts towards the anode plate. Due to the high resistivity of the plates, only a very small portion of the plate is discharged. The signal is collected by pickup strips. Multi-layer RPC improve efficiency and provide trajectory information.

In addition it finds direct application in muon tomography.

As an example, the group has built and deployed a prototype cargo container muon scanner for the company HIDRONAV S.A.; in the framework of an exploratory project on muon tomography of geological structures a prototype detector was built and will be installed in the Lousal mine (Alentejo). Finally, the group designed and built TRISTAN, an autonomous detector for the precise measurement of the cosmic ray flux. It performed two latitudinal surveys from Iberian peninsula to Antarctica, where it is now operating at the Spanish base.

Autonomous RPC

Cosmic-ray experiments and other astroparticle physics experiments often require operating detector arrays in remote locations, with little maintenance, and under different sorts of extreme environmental conditions. The development of an RPC-based technology able to operate outdoors in a reliable and performant way, that are solar powered and have a very low gas consumption is thus of great interest. In particular, sealed RPCs will be a breakthrough in the field, and LIP is close to achieving this goal. In 2020 two sealed RPC with an area of 0.5 x 0.5 m^2 have been in operation for eight months without any malfunction or performance degradation. The results have been presented in the RPC2020 workshop and published.

In the context of R&D for the future gamma ray observatory SWGO, RPC are being pushed to another limit: operation at an altitude of about 5000 m, with the correspondingly low atmospheric pressure. In 2020, chambers developed at LIP have been tested at pressures from, 1000 mB down to 400 mB, corresponding to about 6000 m in altitude. Chambers have successfully passed the robustness and functional tests. In 2021 efficiency tests will be conducted. Adjustments on the number of layers and on the gap width may be performed to compensate for any efficiency losses caused by the low pressure.

RPC-based neutron detectors

Neutrons are a unique probe for revealing the structure and function of matter from the microscopic to the atomic level. Neutron scattering can be applied to a wide range of scientific domains, including physics, chemistry, materials, geology, heritage, and life sciences. Neutron scattering instruments, and in particular the future European Spallation Source (ESS), will be prominent global research infrastructures useful to researchers from academia and Industry.

Helium-3, a stable and very rare isotope of helium, has a high absorption cross section for neutron beams and is traditionally used as a converter in neutron detectors. The shortage of ^{3}He during the last decade and the ongoing construction of new high intensity neutron spallation sources strongly motivated the development of alternative neutron detection technologies, which in addition meet the requirements of a new generation of instruments to be installed at the ESS, namely high-rate capability, high spatial resolution, and fast timing.

The LIP group has introduced and is developing a pioneering concept of a position sensitive thermal neutron detector based on RPC lined with $^{10}B_4C$ as neutron converter. This technology offers very good spatial and time resolution and several practical advantages: high modularity of the design, robustness, good scalability, and low cost per unit area. The group has already demonstrated that it can provide detection efficiencies above 60% and is well suited for neutron imaging (spatial resolution of 0.25 mm).

Our main goal for 2020 was to experimentally demonstrate that the detection technology has the required counting rate capabilities, being able to operate above 100 kHz/cm^2 with the same detection efficiency and spatial resolution. The analysis of data collected in 2019 with detector prototypes featuring lower resistive materials for RPC electrodes showed very promising result. However, the foreseen tests of new materials and new detector designs had to be postponed as a consequence of the COVID-19 pandemic.

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 for further details.

Gaseous detectors and RD51 collaboration

The Gaseous Detectors R&D group develops research in the performance of gas detectors. Its main investigation areas are the study of the drift parameters of both electrons and ions in noble gases and mixtures, with the aim of finding the more suitable active medium for each application. Both simulation studies and experimental measurements are conducted. Recent or ongoing studies include: the electroluminescence xenon TPC used by the NEXT collaboration to search for neutrinoless double beta decay; the measurement of negative ion mobilities, as the use of electronegative dopants in the gas mixture is being considered in several experiments; the identification of ions and measurement of their mobility in mixtures of interest for the RD51 collaboration, that aims at developing novel gaseous detectors with microstructure. Another line of work within CERN's RD51 collaboration concerns R&D on liquid xenon detectors.

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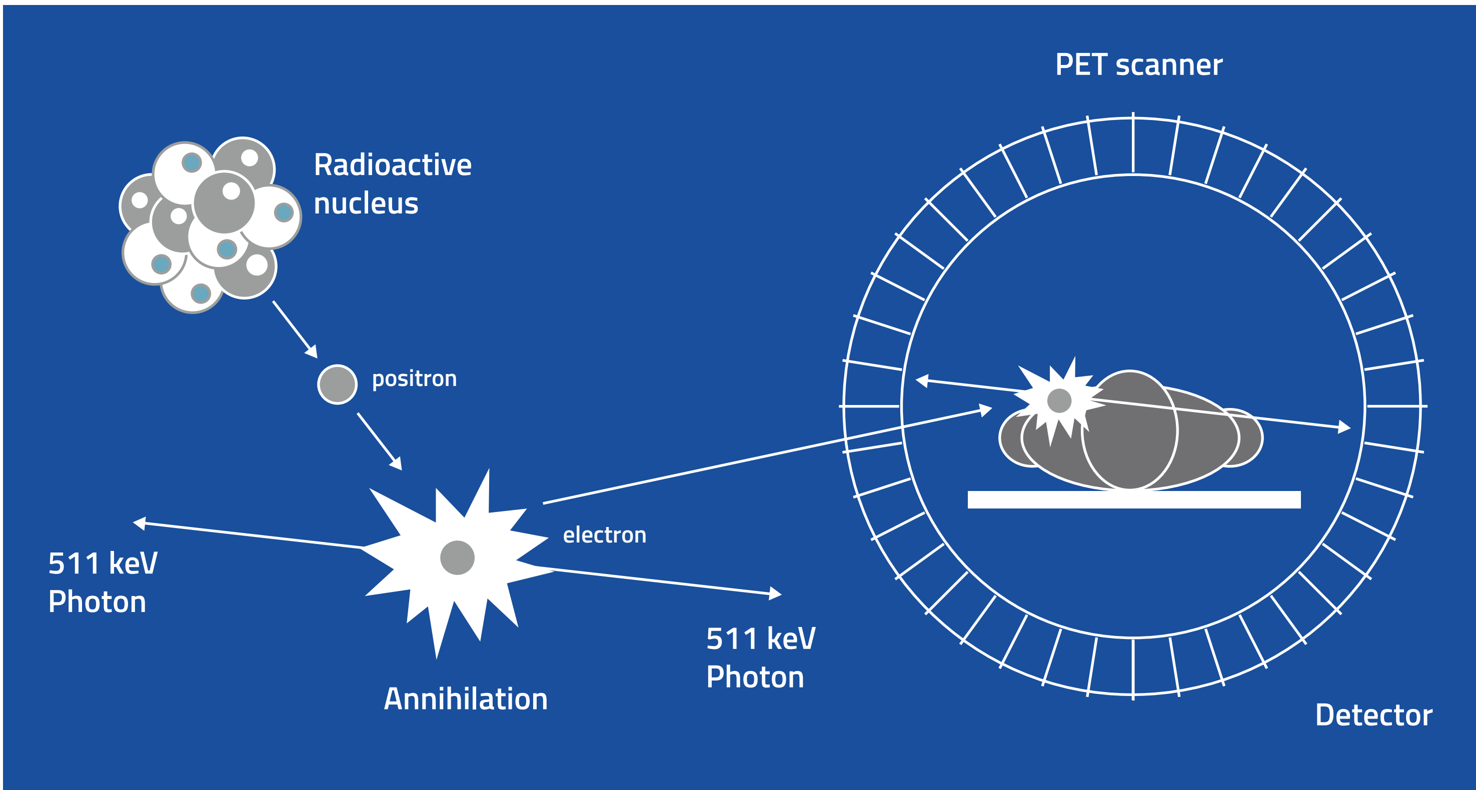
DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

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 campus for nuclear technology, and several hospitals and medical research centers. A center for proton therapy will be installed in Portugal in the near future. LIP is a founding member of the Portuguese Network of Infrastructures for Proton Therapy and Advanced Technologies for Cancer Prevention and Treatment (ProtoTera), jointly with the Portuguese Institute of Oncology Hospital Group, Instituto Superior Técnico, and the University of Coimbra (Resolution of the Council of Ministers n. 28/2018). ProtoTera will promote and develop a national network for research, education and treatment of cancer using advanced technologies, such as proton therapy. In the initial phase, it will coordinate the construction of two nodes in Lisbon and Coimbra, with a 250 MeV proton accelerator coupled to two treatment rooms and one research room in Lisbon, plus a 70 MeV accelerator for the treatment of ocular melanoma and theranostic radioisotope production in Coimbra, which are expected to be operating by 2026. Several research lines and technologies are core to the success of this interdisciplinary infrastructure: improvement in dose distribution, in vivo dosimetry and dose estimation, organ mobility, toxicity, imaging, computing technologies. On the other hand, R&D activities with good cross-fertilization prospects include radiation detectors, imaging techniques and devices, radiobiology, radiation effects on electronic devices, among others. These lists matches the competences of several research groups at LIP with already secured funding in collaborative projects with companies. Close collaborations with international reference centres are being established, namely with CERN, GSI, the Heidelberg University Hospital (Germany), the MD Anderson Cancer Center (USA) and the Trento Proton Therapy Center (Italy). A PhD grant programme was created in 2020, under an agreement between FCT and ProtoTera.



RPC for medical imaging

Positron emission tomography (PET) is an extremely sensitive technique of medical diagnosis. A radioactive marker is injected in the patient's body, releasing positrons in the zone to study. When the positrons encounter electrons from neighbouring molecules, they annihilate, producing two 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 trials. A high-resolution, small animal RPC-PET scanner developed at LIP is installed at ICNAS since 2014. Hundreds of tests have been performed in mice, with goals such as studying degenerative diseases or testing new drugs. This technology is now being applied for human brain PET, in the framework of the project HiRezBrainPET (see text box). 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 involved in neuropsychiatric diseases. The high spatial resolution of the system may play an important role in the characterization of vascular injury or tumors, allowing for a better planning of treatments.

In 2020 a prototype detector head was produced and tested under realistic conditions, validating the mechanical and electronic designs. A preliminary PET image resolution of 0.97 mm was measured, in line with the requirements. The production of the final scanner, with four detector heads, is scheduled for Spring 2021. Some consolidation steps will then be necessary in order to reach a final, commercial product. The next ambitious R&D project would be a full body human PET system, increasing the overall sensitivity as much as 10-fold, with a spatial resolution of 2 mm across the entire field of view. This requires a considerably higher level of funding which is yet to be secured.

Collaborations & partnerships

HiRezBrainPET: neurofunctional cerebral imaging by high resolution positron emission tomography, led by ICNAS-Produção, LIP is main R&D partner

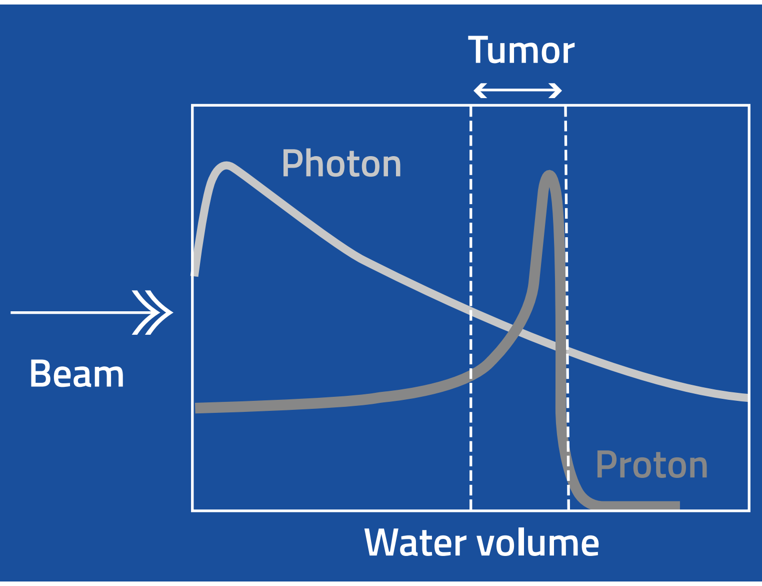
TPPT: TOF-PET for Proton Therapy, led by LIP's spin-off PETsys, PT-Austin collaborative project

PrototerapiaPT+: real-time prompt gamma imaging and microdosimetry, led by LIP, CERN fund.

FCT Strategic Infrastructures Roadmap 2020: LIP is a partner in ProtoTera and Brain imaging network (BIN)

CERN medical physics KT forum: contact person in Portugal is Paulo Crespo (LIP)

Advanced training partnership: co-supervision of PhD and MSc students with J.Seco (DKFZ and Univ. Heidelberg)



Proton-therapy

Comparison betwen a photon and a proton beam in what concerns energy deposition as a function of depth (J. Seco , 2019)

Proton-therapy Instrumentation

Real-time beam monitoring and imagiology

Since several years researchers at LIP are committed to R&D in instrumentation for radiation and particle therapy. The aim is to optimize 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 orthogonal ray (OR) Imaging technique can 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. The rotation-free, low-dose imaging capability of such techniques are two of their great strengths.

On the last few years, both experimental work and ever more realistic simulations have been performed. The goal is to demonstrate beyond doubt to the medical community the usefulness of such techniques in a variety of cases: head-and-neck, pelvis (bone tumor and prostate), lung, total-body irradiation in pediatric tumors, among others. In 2020 experimental results obtained previously by irradiating a phantom with high-energy x-rays from a therapeutical linac at the Coimbra University Hospital Center (CHUC) allowed for a first-time, 3D imaging without rotating neither the irradiated phantom nor the x-ray source using the OrthoCT technique. The results will be submitted for publication in an international scientific journal. As for O-PGI, during 2020 the group undertook extensive simulations including all details required for the optimization and construction of an O-PGI system for monitoring proton therapy treatments in the head-and-neck region.

Dosimetry

LIP has a long experience in the development of instrumentation, simulations, and in the calculation of fundamental physical parameters relevant in dosimetry. In the last two years, the group established a research focus in the areas of high-resolution dosimetry and microdosimetry, which can contribute to improving the data acquisition and analysis of several radiobiology experiments and thus have implications in emerging modalities in radiotherapy. The overall goal is to relate the biological effects of skin irradiation using protons with measurements of dose distribution down to the microscale. For this we propose the possibility of using plastic optical fibres as support to functionalized cells. In 2020 the group started to develop a novel system integrating a high-resolution real-time scintillating fibre dosimeter concept, capable of measuring energy depositions at the sub-millimeter scale, with a functional bioengineered humanized 3D skin model. This project requires competences from different areas and will be performed by a multidisciplinary team including researchers and technicians from LIP but also from BioISI/FCUL and ITQB-NOVA, with experience in bioengineering and radiobiology.

A new line of research started in 2020 is developing simulation tools that allow for the analysis and interpretation of radiobiology studies with multifunctional nanoparticles. Several studies show that the combination of high-Z nanoparticles and external radiotherapy allows for enhanced radiation effect in tumor cells without increasing the patient dose. However, it is not yet clear how the sequence of physical, chemical, and biological mechanisms contributes to the observed effect. The goal of this line of research is to develop skills in the group in Monte Carlo simulations with applications in radiobiology. First work was carried out related to the radiosensitization of cells with Au particles.

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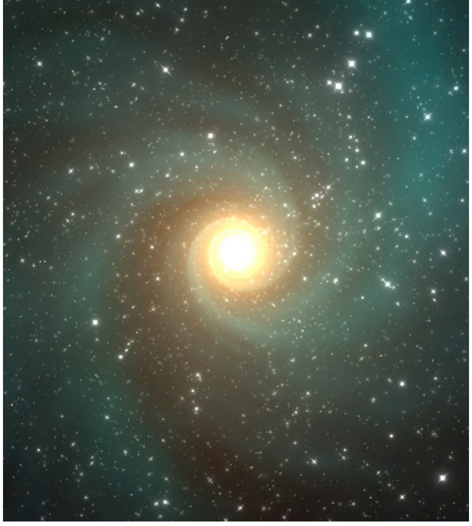

Space applications

Into outer space

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

Radiation environments and effects

Radiation environment in space is the combination of several sources: in addition to solar wind particles emitted continuously by the sun and cosmic radiation coming from outside the solar system, the sun emits sporadically but intensely electrons, protons and ions with energies up to 1 GeV. On top of that, planets with magnetosphere are surrounded by belts of trapped charged particles. The radiation environment affects spacecraft instrumentation and is one of the main constraints for future crewed missions. The detailed knowledge of the radiation environment is essential to establish radiation hazard mitigation strategies. For nearly two decades the LIP SpaceRad group has been addressing questions posed by ionizing radiation in space. Its competences include all the areas on ESA's roaap for this domain: radiation environment analysis and modeling; radiation effects analysis tools; radiation measurement technologies; radiation hardness assurance of Electrical, Electronic and Electromechanical components (EEE).

The JUICE ESA mission to the Jovian system has launch foreseen in 2022. JUICE's radiation monitor RADEM (RADiation hard Electron Monitor) is being developed by a consortium including LIP and EFACEC SA in Portugal, Paul Scherrer Institute in Switzerland, and IDEAS in Norway. LIP has been working on the RADEM detector heads design, response and calibration, radiation analysis, and testing of the radiation effects on the electronics.

We expect the Proton Flight Model calibration to take place in the first half of 2021. LIP is also contributing to the Juice Science Working Team for future analysis of cruise data and cross analysis of RADEM data with other instruments on board of JUICE.

LIP has developed dMEREM — detailed Martian Energetic Radiation Environment Model in 2009 within ESA's contract Martian Radiation Environment Models. dMEREM is available to the community in the Space Environment Information System SPENVIS. The validation of the dMEREM upgrade with data from Mars Curiosity Rover radiation detector in ongoing and will be used in assessing radiation hazards in future crewed missions to Mars and in astrobiology studies.

AlphaSAT is the largest ESA telecom satellite, in geostationary orbit (GEO) since July 2013. LIP has been collaborating with EFACEC SA and EVOLEO SA in different contracts regarding the AlphaSAT radiation Environment and Effects Facility (AEEF). LIP is responsible for the analysis of the in-flight data of AEEF's particle spectrometer and radiation monitor MFS (MultiFunctional Spectrometer), and also of its CTTB (Component Technology Test Bed). Both contracts finished in 2019. Valuable scientific data acquired during five years are being analyzed. LIP is developing an unfolding method to obtain the MFS measured fluxes. Interesting correlations of CTTB data with solar activity were presented at the RADECS2020 conference. A paper on the pioneering study of the effects of radiation in electronics than flew on CTTB, in collaboration with Instituto de Telecomunicações (Univ. Aveiro) will be submitted for publication.

Astrophysics instrumentation in space

Knowledge of the polarization state of radiation provides much astrophysical information that cannot be obtained from intensity alone. In fact, polarimetry provided insight into physical processes occurring in a diversity of systems, from our own solar system to distant galaxies. However, in what concerns high-energy astrophysics (x- and gamma-ray astrophysics) polarimetry has known very few developments, despite its great potential to open a new scientific observational window. LIP's Astrophysics instrumentation (i-Astro) group holds high-level competences in instrumentation for astrophysics with emphasis in x- and gamma-ray polarimetry. The group contributes to the development of instruments with based on semiconductor detector planes (CdTe, CzT, Si, Ge), scintillators (CsI) or gas-filled detectors with polarimetric capabilities.

The group develops its research activities in the framework of mission proposals to ESA and NASA in the x- and gamma-ray domains. Currently iAstro is part of EU's H2020 AHEAD (Activities in the High Energy Astrophysics Domain) project, prolonged at least until 2024, and we are developing a compact, CubeSat-compatible (CubeSat is a miniaturized satellite type for space research made up of multiple small cubic modules) Compton Telescope prototype that offers game-changing polarimetric capability in the few hundred keV range. Furthermore, we are part of NASA's AMEGO (All-sky Medium Energy Gamma-ray Observatory).

In addition, we are currently leading two projects selected in ESA calls. The project "Ageing of Ge/Si and CzT samples for sensors and Laue lenses" was selected in the CNES/ESA Announcement of Opportunity to test materials for space applications directly in the low-Earth orbit environment, through use of Bartolomeo's "Euro Material Ageing" facility onboard the International Space Station. The experiment is led by LIP in collaboration with University of Beira Interior and several Italian research institutions, namely INAF, University of Ferrara, Active Space, and Istituto dei Materiali per l'Elettronica e il Magnetismo (IMEM, Parma). This research line aims to characterize the effects of orbit radiation environment on a CdTe-based instrument of the type that could be used in a future gamma-ray observatory for a Low-Earth Orbit (LEO) mission.

Within ESA's program BEXUS (Balloon EXperiments for University Students), and under the guidance of LIP researchers, a group of students from the University of Coimbra proposed the experiment STRATOSPOLCA — BEXUS STRATOSpheric POLarimetry with Cadmium Telluride Array experiment, which was selected to fly. The STRATOSPOLCA flight model was developed, the detector and electronics were integrated and tested at LIP laboratories. The ballon launch was postponed to late 2021 due to the COVID-19 pandemic.

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Computing

▪ Scientific computing

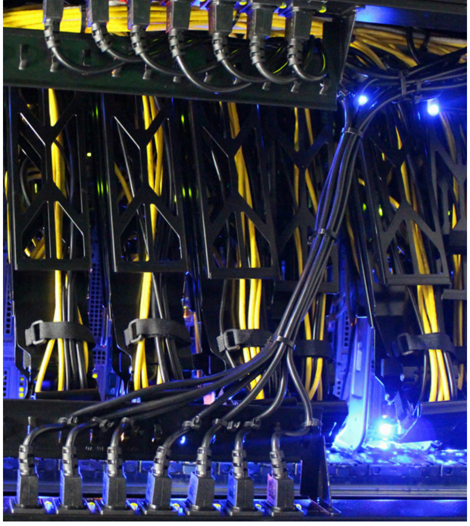
Scientific research requires increasingly higher data storage and processing capacities that stress the limits of information systems and related technologies.

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.

LIP has growing expertise in data science and big data analytics that open opportunities for knowledge transfer and for addressing societal changes. The recent arrival of the SPAC group very much strengthens this domain and opens completely new research lines in social physics and complexity.

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, participating in the FCT infrastructures, and in the enabling of future policies for scientific computing and open access.



Scientific Computing

Enabling Compute Intensive and Data Intensive Science

The LIP computing groups have extensive knowledge and experience in scientific computing, excellent international relations and integration in scientific e-infrastructures, with users from multiple disciplines and organizations, participate in the FCT infrastructures, and in the enabling of future policies for scientific computing and open access. LIP has growing expertise in data science and big data analytics that open opportunities for knowledge transfer and for addressing societal changes. The recent arrival of the SPAC group very much strengthens this domain and opens completely new research lines in social physics and complexity.

Distributed computing and digital infrastructures (GRID)

The LIP Distributed Computing and Digital Infrastructures group provides information and communications technology (ICT) services to LIP. These services support research, innovation, education and outreach, and administrative activities. The group has extensive experience in delivering compute and data oriented services for simulation, data processing and analysis.

In particular, the group operates the Portuguese Tier-2 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 einfrastructures to serve the LHC experiments. In 2020 the LIP Tier-2 in the WLCG delivered more than 83 000 000 HEP Spec06 hours amounting to approximately 110% of the pledged capacity.

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 data processing using cloud computing, High Throughput Computing (HTC), High Performance Computing (HPC), and machine learning.

The group is currently participating in the H2020 projects EOSC-hub, EOSC-Synergy, EGI-ACE, EuroCC and C-Scale.

Based on its 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. INCD is co-managed by LIP, FCCN and LNEC. The group is also engaged in national activities related to high performance computing in the context of the National Advanced Computing Network (RNCA). Both INCD and RNCA are part of the National Roadmap of Research Infrastructures published by FCT in 2020.

In 2020 the INCD infrastructure has delivered more than 47 000 000 CPU hours of batch and cloud processing. LIP and INCD supported projects in the area of Particle Physics, Biomedicine, Structural Biology, Coastal Engineering, Oceanography and Biodiversity among others. The INCD center in the north, hosted by LIP Minho, is supporting HTC and HPC applications that exploit the Bob supercomputer under an agreement with FCT. LIP is managing the data storage systems for this supercomputer, which is split in two partitions managed by INCD and MACC (Minho Advanced Computing Centre).

LIP collaborates with FCT also in the framework of RNCA. The laboratory is part of the group that will establish the foundations and rules of participation for this network. In this context, LIP collaborated in the definition and evaluation of the first call for advanced computing projects (CPCA). This first call will provide computing time in operational centers of the RNCA network over a period of six months. INCD is one of such centers and will deliver cloud and HPC capacity to support 42 computing projects starting in January 2021. INCD will also support projects from the FCT call AI 4 COVID-19.

The group activities bridge at international level with science related infrastructures and initiatives such as the European Grid Infrastructure (EGI), Iberian Grid Infrastructure (IBERGRID), European Open Science Cloud (EOSC) and EuroHPC. In this context the group collaborates with several international research communities beyond particle physics.

In the IBERGRID and EGI context, LIP ensured the national liaison and coordinated the operations of the Iberian distributed computing infrastructure and its integration in the pan-European EGI infrastructure. IBERGRID delivers federated cloud, HPC and HTC to support international projects and initiatives of common interest to Portugal and Spain.

LIP continued an active participation in the EOSC-Synergy project that aims at the alignment of national infrastructures and policies in Spain, Portugal, UK, Czech Republic, Germany, Slovakia, Poland and the Netherlands towards the implementation of the European Open Science Cloud (EOSC). LIP is coordinating the work package on fostering service adoption where new tools are being developed following a quality based approach applied to software and services.

In the context of the EuroHPC initiative, which aims to develop a world class supercomputing ecosystem in Europe, LIP participated in the preparation of the EuroCC project to deploy a long term network of national advanced computing competence centers in Europe. The project started in September 2020 and LIP participates in the national competence center in the areas of training, support and consulting for research and industry.

LIP also coordinates the national activities related to communication, dissemination and outreach. Also related to HPC, the project BigHPC started in March a collaboration with industry, TACC (Texas Advanced Computing Center), and INESC-TEC to develop a management framework for consolidated Big Data and HPC.

The group will continue exploiting synergies with other organizations, especially in the context of INCD, aiming at collaboration in the implementation of platforms and solutions adapted to the needs of these user communities. Examples are GBIF, LifeWatch/PORBIOTA, Elixir/BIODATA and CoastNET. Finally participation in further R&D&I projects will be pursued in the context of ongoing collaborations (IBERGRID, EGI, INDIGO-DC) exploiting opportunities in the context of Horizon Europend Digital Europe.

Social Physics and Complexity (SPAC)

SPAC uses large scale computational tools to study societal challenges, especially in disease forecasting, human behavior, and public policy, using a complex systems approach. SPAC joined LIP during the second half of 2020. Its work is mainly funded by an European Research Council (ERC) Starting Grant to the group's 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, right now, the Digital Revolution is offering radically new ways to study complex human behaviours. There is a growing perception that physics will be fundamental to study sociology and even psychology and leading scientists are calling this new science "Social Physics" and arguing that, in some ways, complexity science will study the physics of human interactions. Therefore, SPAC is very multidisciplinary with members having backgrounds in Physics, Mathematics and Computer Sciences, but also in Biology, Neurosciences, Psychology, and Law. Together, the group takes advantage of the so-called "Big-Data Revolution" and aims at understanding how individual behaviour impacts on society. SPAC also focuses on the risks that these upcoming technologies might entail, from privacy to biases, and works to establish guidelines for ethical uses of data science and artificial intelligence.

In 2020 SPAC's efforts have been focused on studying two parallel pandemics: one caused by a virus on real contact networks and the other driven by misinformation, mostly on online social media. Research on the current pandemic has led to two working papers, both already on MedRxiv and submitted for publication. In parallel, several group members are actively collaborating with national health authorities on mitigation and information capacity building. The group finished one FCT-funded project, on reducing antibiotic overprescription, still managed by the PI's previous institution (NOVA SBE). This project was a pilot of current efforts to improve public administration through data science and artificial intelligence, and will give rise to one research paper and one policy report. The group finished a long-term project on analysing 40 years of Portuguese political discourse. SPAC's PI is strongly involved in science communication and outreach and finished in December 2020 a long-term collaboration with Instituto Gulbenkian de Ciência, to improve critical thinking, science education and citizen science.

SPAC intends to internationally cement its position in social physics research and help improve the current national research capacity, mostly through infrastructure creation and postdoctoral training. Research lines will focus on understanding properties of spreading on networks (of information, misinformation or pathogenic agents) and human behaviour, from the individual to the societal levels. In a broader way, the development of the field of "Social Physics" will rely strongly on the concept of treating humans as particles, and interesting research will emerge from applying theoretical models from physics (ex. fluid dynamics, statistical physics) and simulations (ex. Monte Carlo) to the human interactions. Therefore, it is expected that strong collaborations will arise with different LIP research groups. These collaborations can easily expand to international partners, including CERN. Finally, the group accepts its strong social responsibility and, parallel to scientific output, consistent efforts will be developed to improve public understanding of science and of the current risks brought about by the digital revolution.

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Research Infrastructures & Competence Centres

Reasearch Infrastructures ▪ Computing ▪ LOMaC ▪ Mechanical workshop ▪ Detectors laboratory ▪ e-CRLab ▪ TagusLIP laboratory

Competence Centres ▪ Monitoring and Control ▪ Simulation and Big Data

LIP's **Research Infrastructures** are central in the laboratory's activities. They provide support to the R&D activities of the LIP research groups and services to external entities. Just like the Computing Infrastructures, the Mechanical Workshop (MW) and the Detectors Laboratory (DL) in Coimbra were created at LIP's foundation in 1986 to support research activities and provide LIP with the necessary conditions to give effective contributions to detector development and construction in CERN collaborations, using the high-level existing expertise. The research infrastructures in Lisbon, initally linked to specific projects or groups, became wider in competences and use: LOMaC (optics and scintillating materials lab), created in 1992 in the context of R&D for the ATLAS TileCal calorimeter; and the electronics labs TagusLIP and e-CRLab, initially linked to medical physics and cosmic ray experiment instrumentation, continuing the instrumentation for data acquisition system activities in Lisbon.

Competence Centers at LIP are designed to be light and flexible horizontal structures joining 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.

REASEARCH INFRASTRUCTURES

Computing

LIP Computing Infrastructures provide scientific computing services to LIP and to a wider community in the context of the Portuguese National Distributed Computing Infrastructure (INCD), of which LIP is the technical coordinator. INCD joins LIP, LNEC and FCT-FCCN to provide advanced computing and data oriented services to the Portuguese scientific and academic communities. INCD is a digital infrastructure of FCT's Research Infrastructures Roadmap and is classified as a technological interface center by ANI. INCD supports all scientific and technological domains enabling computing and data intensive research. INCD also supports the use of international resources through the connection to European digital infrastructures such as EGI, IBERGRID and WLCG.

In 2020 INCD operated and made available computational and data services through its operational centers in Minho and Lisbon, providing more than 32,600,000 hours of batch processing and 9,100,000 hours in cloud computing to more than 50 institutions. The INCD resources were also used to support teaching and advanced training. In the European project EOSC-Synergy, INCD contributed to policy harmonization and federation of thematic services, data and computing resources within the scope of the European Open Science Cloud (EOSC). As member of the National Advanced Computing Network (RNCA), INCD participated in the first edition of the FCT's Advanced Computing Projects Call (CPCA) as an operational center supporting 40 ongoing computational projects.

As part of the fight against the SARS-CoV-2 pandemic, INCD collaborated with National Health Institute (INSA) providing cloud computing resources to assist in the study of the genetic diversity of the new coronavirus. The INSaFLU platform was used to analyze all SARS-CoV-2 genomes generated to date in Portugal. The complete platform is being migrated to INCD.

REASEARCH INFRASTRUCTURES

Laboratory of Optics and Scintillating Materials (LOMaC)

LOMaC was created in the context of the ATLAS TileCal project in the 1990s. The entire set of plastic wavelength shifter (WLS) fibres 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, including DELPHI, SNO+ and the ATLAS ALFA luminosity monitor. LOMaC's expertise is centered on the preparation and test of plastic WLS and scintillating optical fibres, scintillators and related devices for particle 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.

In 2020 the work focused mostly in three projects: i) development of a high-resolution dosimeter prototype (sub-millimetric resolution), in collaboration with the e-CRLab and the Dosimetry group. A setup for the measurement of the cross-talk between scintillating optical fibres with different cross-sections (1 mm, 0.5 mm, 0.25 mm) was prepared; ii) support to the development of the high-voltage boards for the TileCal upgrade, in collaboration with the e-CRLab and the LIP ATLAS group, in particular by setting up a test bench for the new TileCal high-voltage system; iii) radiation hardness studies of TileCal scintillators and WLS fibres, focusing on HL-LHC as well as on future detectors. The study used data from the TileCal calibration systems, collected along the years of LHC runs.

REASEARCH INFRASTRUCTURES

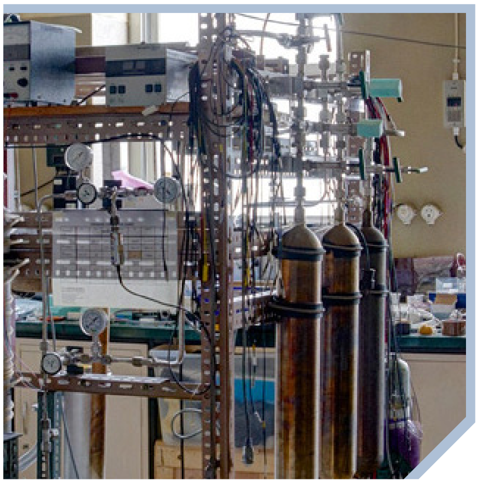
Mechanical Workshop (MW)

LIP's Mechanical Workshop was established in 1986 to support the experimental activities performed in collaboration with CERN. The available equipment and highly qualified staff allow the MW to offer a large spectrum of mechanical services, from project design to production and testing. In particular modern CNC (Computer Numerical Control) machines (including a large area 3x2 m^2 machine) allow for complex jobs to be performed. Today the MW provides services to research groups both inside and outside LIP and also to external companies.

LIP's Detectors Laboratory and Mechanical Workshop have complementary competences, and many projects at LIP require the services of both facilities. Over more than three decades, the two infrastructures assured excellent quality support for detector R&D and played a fundamental role in the success of LIP's participation in large international collaborations.

Despite the COVID-19 pandemic that forced the MW to close for about a month, 2020 has been a year with 55 open worksheet (to be compared with 54 in 2019, 60 in 2018) and 100% of the time occupied.

Some of the largest projects were the design of the complete mechanics for HrezBrainPET and construction of the prototype detector head, parts of the mechanical system for the laser calibration system for protoDUNE and the mechanics for two sectors of HADES RPC-TOF-FD detector. Related to COVID-19, the MW produced protection systems for the University of Coimbra and several pieces for the emergency openAir initiative emergency ventilator.



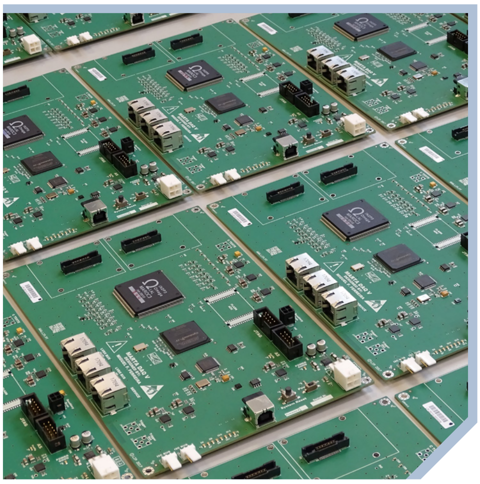
REASEARCH INFRASTRUCTURES

Detectors laboratory (DL)

The Detectors Laboratory was created at LIP's foundation in 1986 with the aim of supporting the experimental activities developed by the research groups. Along the years the DL has been continuously updated taking into account both general and more specific needs. Today the available equipment and technical staff allow for 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. DL services span from the project design phase to installation and maintenance, following a procedure similar to industry's.

In 2020 the main activities of the DL concerned the R&D and production of different types of large area Resistive Plate Chambers (RPC) used in experiments and projects in which LIP is involved, and the support to LIP groups in their R&D activities. Products and services delivered to external institutions through contracts, while there was a reduction with respect to previous years due to the COVID-19 pandemic. Particularly relevant was the work done for the MAREFOZ Laboratory. A Spark Chamber was sold to the Science Center of Luxembourg. At the customer's request new features were added.

While the pandemic impacted the activity plan in several ways, the DL was able to keep its commitments, and has been a partner in initiatives to help fighting COVID-19 in which LIP members were involved. R&D and production of novel equipment for outreach purposes was a goal postponed to next year due to the pandemic. As a highlight of 2020, the first real size prototypes of a sealed RPC were built and tested.



REASEARCH INFRASTRUCTURES

Cosmic-rays electronics laboratory (e-CRLab)

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 (PCB) and to produce simple PCB prototypes. The production and assembly of complex PCB is outsourced. There is also the capability to do rework in PCB boards. A small set of mechanical tools allows for the production of simple detector prototypes mainly for proofs of concept.

The e-CRLab has the responsibility of the development, deployment and commissioning of the electronics for the MARTA detectors to be installed at the Pierre Auger Observatory. The front-end electronic (based in the MAROC ASIC) was deployed and the slow control, central unit and interface boards were developed. Nevertheless, traveling to Argentina and field work were severely limited in 2020 and the commissioning of the first MARTA unit was postponed. A new hodoscope setup has been installed at LIP in Lisbon, consisting of two MARTA RPC planes separated by 3 m. It will be used to test the developed systems. The MARTA electronics will be used for other projects, including a muon tomography device for the Lousal mine, and possibly also projects external to LIP. The e-CRLab has been involved in the development of the high-voltage (HV) system for the ATLAS TileCal upgrade, namely in the development of the HVsupplies board and in identifying and proposing solutions for the several test setups and interconnects.

REASEARCH INFRASTRUCTURES

TagusLIP Laboratory

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 laboratory is equipped with the necessary instrumentation for R&D on radiation detectors and associated electronics and data acquisition, and is licensed for the use of radiation sources needed to develop and test instruments in nuclear medicine. The development of TOFPET1 ASICs for positron emission tomography (PET) time-of-flight (TOF) applications was at the origin of the creation of the startup company PETsys Electronics in 2013.

In 2020 the main users of the TagusLIP Laboratory were the LIP-CMS group and PETsys Electronics. On the LIP side the activities concern the responsibilities on the Phase-2 Upgrade of the CMS experiment. The development of the new ASIC TOFHIR2 board for the new CMS Barrel Timing Detector was pursued in collaboration with PETsys. The microelectronics design was performed by PETsys following the specifications of the CMS group (LIP-CERN Collaboration Agreement KN436/EP). LIP was responsible for the testing, characterization and integration. A first version of the chip was designed and a second one with improved performance was submitted for fabrication. The first prototype of the BTL front-end board integrating six ASICs was validated. PETsys leads the consortium Time-of-Flight PET for Proton Therapy, in which LIP is also involved, and has the responsibility of developing the readout system. A full readout system based on the TOFPET2 ASIC was developed by PETsys for PANDA experiment at FAIR. The final detector will consist of 28,800 channels.

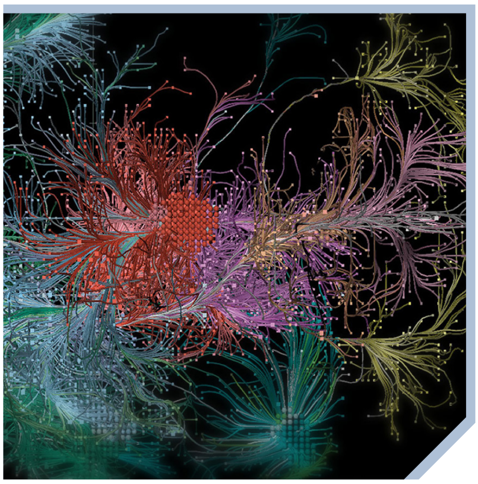
COMPETENCE CENTRES

Monitoring and Control (CCMC)

The CCMC gathers expertise in design, implementation and operation of monitoring and control systems accumulated by LIP groups. Besides facilitating knowledge sharing (including sensors, electronics and software), the CCMC intends to establish partnerships and contracts with other research laboratories and companies as a means to transfer knowledge and solutions into the community. The focus is on the development of user-specific solutions for monitoring and control, including all hardware, firmware and the required software for data handling, delegating hardware manufacturing to LIP's scientific infrastructures.

In 2020 the CCMC continued the development of the end-user software framework meant to be the basis solution when deploying its products. It is designed to be easy to adapt to the client's needs and to interface with virtually any monitoring and control hardware, while supplying a user friendly front-end for data display and handling. A graphical user interface developed by the LZ team is being integrated with the database tools developed within the CCMC. The CCMC participated in the LIP Internship Program.

The main external client was the ECOTOP group from MARE (Univ. Coimbra). The first two heart-rate and temperature monitors for nesting birds were produced, tested and deployed in field conditions. A new batch of 25 monitors was then produced, featuring important improvements in hardware and firmware, allowing to extend the recording time and eliminate data acquisition dead-times. CCMC and ECOTOP are actively searching for funding to build a device to control and monitor environmental parameters of nests in the natural habitat of birds.



COMPETENCE CENTRES

Simulation and Big Data (SimBigData)

At LIP there is a wide range of competences in data analysis and simulation tools, including physics models, Monte Carlo generators, detector simulation tools, big-data analytics and data mining. The ability to fully benefit from such competences requires exploiting synergies between groups and identifying key areas in which we can contribute in a competitive way. This is the purpose of the SimBigData CC.

Concerning Simulation, the vast know-how in the GEANT4 toolkit and the contributions to the GEANT4 collaboration play a central role, while in Big Data the team is consolidating experience in anomaly detection in contexts where uncertainties play an important role. Training and knowledge sharing are additional goals.

Simulation-related activities in 2020 included: introductory course on GEANT4 at Univ. Minho (Feb. 2020); support and maintenance of the Advanced Example LIP is responsible for within the GEANT4 collaboration; support to the LIP research groups in applications using mainly GEANT4, GEANT4-based simulation tool MEGAlib, EnsarRoot framework (uses Virtual MonteCarlo platform and GEANT4 for transport) and LIP's ANTS2 general-purpose front-end (interfaced to GEANT4). A method to implement geological topographic maps in GEANT4 is being developed.

In the context of the FCT-funded BigDataHEP the development of machine learning techniques for the detection of rare events at colliders resulted in several publications, presentations and theses; a new partnership with the company Tellspec was established in the context of the analysis of data collected with portable infrared spectrometers and possible applications in production line quality control; collaboration with the gravitational waves community through COST action CA17137.

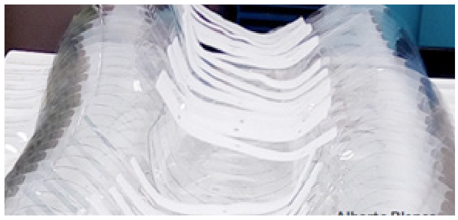
LIP against COVID-19

Emergency Ventilator

A LIP team led by Paulo Fonte, within a group of volunteers gathered in the context of #ProjectOpenAir, developed a new emergency ventilator concept meeting the requirements for COVID-19 patients. It can be built quickly with low cost materials that are easy to even in times or regions with logistic difficulties. The proof of concept was carried out at LIP-Coimbra, with the collaboration of the DL and MW, being functional and available for replication from mid-April 2020.

Protection Visors

COVID-19 face protection visors to be used by health professionals have been developed at LIP, reusing material left over from the production of MARTA cosmic ray detectors. The production was performed with the voluntary collaboration of the MW staff.



LIP Computing

LIP with INCD assisted the National Health Institute (INSA) in the study of the SARS-CoV-2 genetic diversity, providing Cloud Computing resources for INSAFLU ,an online bioinformatics platform for analysis and comparison of virus genetic information.

Within the EOSC-synergy project LIP is part of, an instance of a Galaxy portal for the processing of genomic data has been setup. The portal is freely accessible and includes data on coronavirus and specially samples from SARS-CoV-2 (COVID-19) daily updated from the public international databanks, as well as some key tools for identification of mutations, phylogenetic analysis, sample processing and visualization.

SPAC Research

The **LIP SPAC** group develops activity directly related with the current pandemic:

- Research on the current pandemic has led to two working papers, both already on MedRxiv and submitted for publication.
- Several group members are actively collaborating with national health authorities on mitigation and information capacity building.
- The group has also published opinion articles and commentary on pandemic control.

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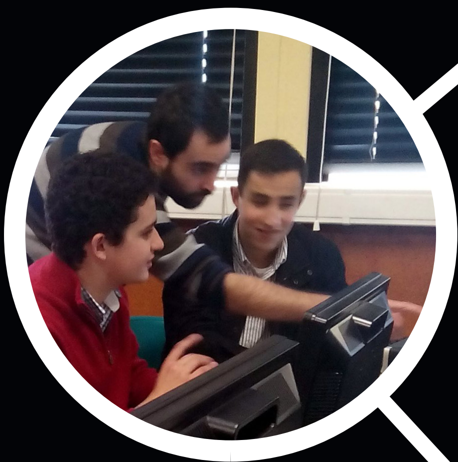
Knowledge transfer and **societal impact**

Radiation, health and **environment**



Advanced training

Education, communication and **outreach**

LIP

science and society

Knowledge transfer and societal impact

Fundamental science drives innovation in the long term, and particle physics technologies have a wide range of applications, and the potential to respond to societal challenges. LIP is engaged on specific objectives that support public policies in the science, health, economy, social and environmental sectors. In the last few years, LIP has made impactful contributions by developing excellent fundamental and applied research; attracting talent; bridging scientific knowledge and business innovation; developing diagnosis and therapy methods; focusing on science and technology culture and education, supporting the school community; promoting digital competences and technology accessibility towards social inclusion; and contributing to increase computing power and expertise namely in health- and environment-related research and in the scientific community at large. In the coming years such public policy objectives will be pursued and supported. LIP represents Portugal in several international forums addressing links to society: CERN KT for medical applications, HEPTech, Teacher and Student forum, European Particle Physics Communication, International Particle Physics Outreach Group (co-chaired by LIP), and several European computing infrastructures and initiatives.

Collaborative and innovation projects

The list of companies the LIP groups have collaborated with in the last 5 years includes Adductio, Bosch, Cabelte, Dialog Semiconductors, EFACEC, EVOELEO, Grupo ASSEC, HIDRONAV (Spain), ICNAS-Produção, Ideas (Norway), Kinetic (UK), Nielsen, NuRise, PETsys, Siemens, Silicon Gate, Systion, Tellspec and Wavecom. Some of the main Portuguese research units and other public institutions we collaborated were CEFITEC/NOVA, CFTC/FCUL, CFTP/IST, CHUC, CTN/IST, FCCN/FCT, GHIPOFG, Hospital de Santa Maria, IBEB/FCUL, ICNAS, INCD, INESC-ID, INESC-TEC, LNEC, MACC, MARE.

LIP's experience in common projects with companies and with other research units must be used to leverage its innovation impact within our fields of expertise, namely through collaborative projects with companies and other external entities, in consortia of various dimensions. Strategic areas are healthcare, space application, data science and digital technologies. Both national and international collaborations will be established, namely in the context of the Strategic Infrastructures that LIP is connected to and of international collaborative funding programmes, such as the ones with USA universities (e.g. Portugal-Austin).

LIP keeps a close connection with the representative of Portugal in the CERN KT forum (José Antão, from ANI), in the CERN KT forum for medical applications (Paulo Crespo, from LIP) and HEPTech, an European Network devoted to KT from large scale HEP science projects and research facilities (José Carlos Silva, from LIP). Such forums will be further explored with the goal of increasing the industrial return to Portuguese institutions.

Internationalization of Portuguese companies

As CERN's reference institution in Portugal and recognised partner of ESA and of PT Space, LIP will maintain a close partnership with the Portuguese Industrial Liaison Officer (ILO) for CERN and with ESA's Industrial Policy Committee (IPC) representative at PT Space. This has been a successful way to promote the internationalization of Portuguese companies in the past and it will be strengthened by proposing partnerships, providing support or facilitating a first contact. LIP is a member of PERIN and will actively develop efforts to strengthen the collaborations with this network.

Articulation with FCT's Roadmap for Research Infrastructures

LIP has direct links with Scientific Infrastructures included in the National Roadmap: LIP is the technical coordinator of the National Distributed Computing Infrastructure (INCD) and a member of the Nacional Advanced Computing Network (RNCA); LIP is a founding member of ProtoTera; LIP is the main technological partner in several projects of the National Brain Imaging Network (BIN); LIP is committed to work with the Portuguese Space Agency (PT Space), reinforcing its projects with ESA and with national and international industrial and academic entities. The areas of healthcare applications, space exploration applications, and information technologies have the potential to improve both the quality of life (reinforcing the quality of health, education and research networks) and the economy (improving the competitiveness of Portuguese companies).

Training for employability and qualification

Directly involve graduate students in collaborative, multidisciplinary, innovation projects with companies and other external entities, through internships, technology-oriented advanced training and the inclusion of an applied research component in their projects. This will enhance their level of employability in the private sector and contribute to increase the qualification of the human resources in Portuguese companies.

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

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 concentration 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. The group's main laboratory for the radon study is the LabExpoRad. The facility is integrated in UBIMedical, the University of Beira Interior health technology park. The laboratory is equipped for the detection of radon in water and air. In the past few years the work focus was on the measurement of radon in the air and water in Angola and the study of radon exhalation from building materials.

Advanced Training

The ability of LIP to attract, engage, train and support university students in its fields of activity is paramount for the future of the laboratory. The advanced training (AT) group coordinates and promotes actions dedicated to university students at the several levels (undergraduate, master, doctoral), providing high-quality training and ensuring LIP's capability to attract, engage and retain research students. In 2020, the COVID-19 pandemic impacted the Lab's normal activity, having also disrupted several training events. On the one hand several of the activities scheduled since mid-March were postponed (now tentatively to late 2021). This was the case of events for which the possibility of social interaction and spontaneous in-person discussions were deemed more critical. On the other hand, many of the AT events were held remotely and even explored new opportunities facilitated by the remote working environment. Below we give an overview of what are the main advanced training event series at LIP, stating in particular what happened in 2020.

Graduate students

LIP permanently hosts tens of PhD, master and bachelor students, who actively work within its research groups. This enhances the close connection between LIP and associated universities, namely in Lisbon, Coimbra and Minho. Various actions are directed towards the PhD and master students working at LIP, and also in the framework of international PhD networks. During 2020, LIP hosted over 70 graduate students (about 30 PhD and 40 MSC). In 2020 FCT and LIP promoted calls within the PhD programmes PT-CERN and ProtoTera. In total, 17 grants have been awarded.

IDPASC school

LIP coordinated the IDPASC international network. The IDPASC school takes place every year in a country of the IDPASC network. consists of two weeks of lectures, discussion sessions and a final exam. The 2020 edition, foreseen to take place in Nazaré (Portugal) has been postponed, now tentatively to late 2021.

LIP/IDPASC Students Workshops

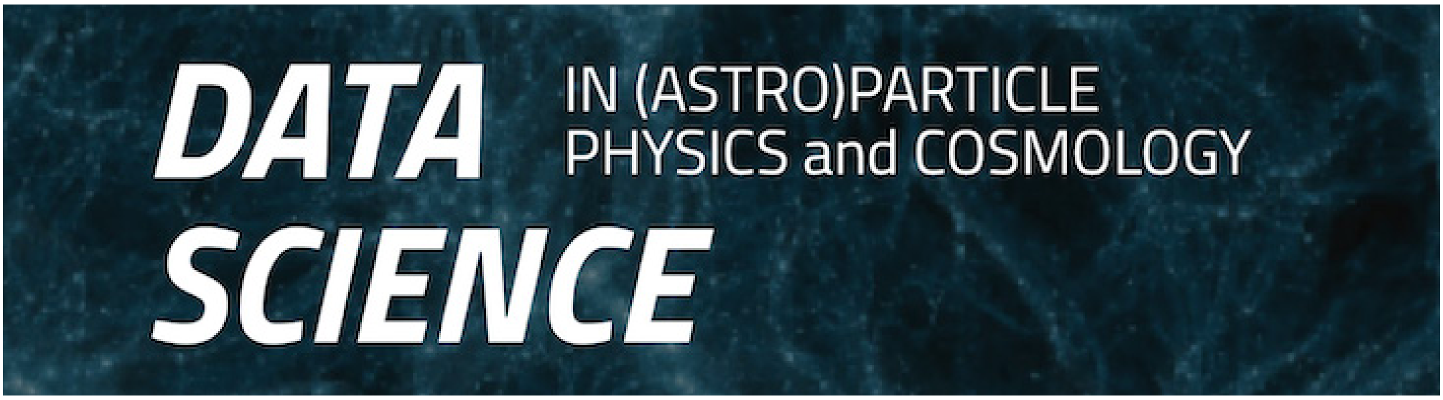
Two-day meetings in which all PhD students present the status of their work to an audience of graduate students and researchers. Keynote lectures on selected topics (including some suggested by the students) are also part of the program. The 6th IDPASC/LIP PhD students workshop took place online, with over 70 participants; it included 25 PhD student talks; keynote talks; and 7 master student posters, including short video presentations.

Student awards 2020

A balloon experiment proposed by students from the University of Coimbra supported by LIP was selected by ESA. A PhD student (A. Carvalho) received an ATLAS PhD Grant. Two young researchers (K. Shchelina, T. Niknejad) have each received recognition awards by the CMS Collaboration.

LHC Physics Course

Consists of close to 20 lectures covering introduction to the standard model, detectors, statistics, and overall research, held from March through June. The course has a final evaluation and gives credits to PhD students at IST. In 2020 the course was given online. The typical attendance of each lecture was 5-10 students. Five students gave a final presentation followed by discussion that served as final evaluation.



School & Symposium on Data Science

Has the double goal of providing advanced training and tightening links to other institutions, particularly with the non-academic sector. In 2019 the school had 80 students and the symposium over 100 participants, with representation from 20 companies. The event included a public session attended by over 100 people. This has now become a regular event series. The 3rd edition, to be held in Coimbra in 2020, has been postponed to late 2021.

Undergraduate students

LIP Internship Program

Is our flagship initiative for undergraduate students. The 2020 edition was not noticeably affected by the pandemic: the standard dates that had been defined earlier were kept, and it received the usual level of enthusiasm, on the part of both supervisors and students, as inferred from the numbers of projects proposed (39) and students subscribed (67), involving all three LIP nodes. The program did nonetheless move to an entirely online format. This circumstance did clearly pose new challenges, which were however addressed by adapting and deploying correspondingly new ideas and tools. LIP referencing of scientific documentation was fully implemented, spearheaded by the novel LIP student papers.

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. Furthermore, LIP regularly participates in events organized by physics student associations at the different universities.

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 2020, some schools and workshops scheduled for the beginning of the year could still be held:

- 5th Lisbon Mini School on Particle and Astroparticle Physics: co-organized by LIP and CFTP, it was held in Costa da Caparica in February and gathered 30 undergraduate students from several universities.

- 1st LIP GEANT4 introductory course: organized by the LIP Simulation & Big Data Competence Center, it took place in Braga in February. It was attended by 17 participants from the fields of high-energy physics, material science and medical physics. Further sessions that had been planned for Coimbra and Lisbon later in the year were postponed.

Education, communication and outreach

Education, Communication and Outreach (ECO) are part of LIP's societal role and essential for the recognition of its work. The LIP-ECO group exists to boost, integrate and coordinate the laboratory's activities in this domain. The activities of LIP-ECO involve all three LIP nodes.

In 2020 the vast majority of the LIP community was in remote work mode. An internal communications priority thus was to keep the community linked and cohesive throughout the year. Concerning external institutional communications, the communication of the ESPPU approval, the LIP-News Bulletin featuring Proton Therapy in Portugal, and the support to the preparation of the application to the Associate Laboratory call were some of the main tasks. Furthermore, an increase in human resources allowed for progress in ongoing work related to the consolidation and renewal of the visual identity of LIP and to the production of promotion material.

Education and outreach activities were more severely affected, as from mid-March on all events were either canceled or held remotely. In particular, the 2020 CERN Portuguese Language Teachers Programme was cancelled. Nevertheless, an effort to keep in touch with the school community was maintained, and towards the end of the year a few very successful online events were held. Summer internships, the wide participation in Ciência Viva's "Space goes to school", and the European Researchers Night were some of the highlights. LIP gives support to experimental activities in schools and develops equipment for exhibition and demonstration purposes, such as the particle detectors at the science centres of Constância (spark chamber) and Lousal (RPC-based muon detectors) and LIP's cloud chamber, with the collaboration of its scientific infrastructures and competence centres.

Partnerships

LIP has several national and international partners in communication, outreach, and support to education. At national level we are partners of Agência Ciência Viva and of the Portuguese Physical Society. LIP is a member of the International Particle Physics Outreach Collaboration, the European Particle Physics Communication Network and the CERN high-school students and teacher forum. Pedro Abreu, co-coordinator of LIP-ECO, is currently serving ad IPPOG co-coordinator.

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2020 communication highlights

Media

The 2020 media highlight was the coverage by the reference daily newspaper Público of the approval of the European Strategy for Particle Physics Update by the CERN Council in June. Two pages were devoted to the topic, with a long article and an interview with Mário Pimenta, Portuguese Delegate to the CERN Council and President of LIP.


CIÊNCIA

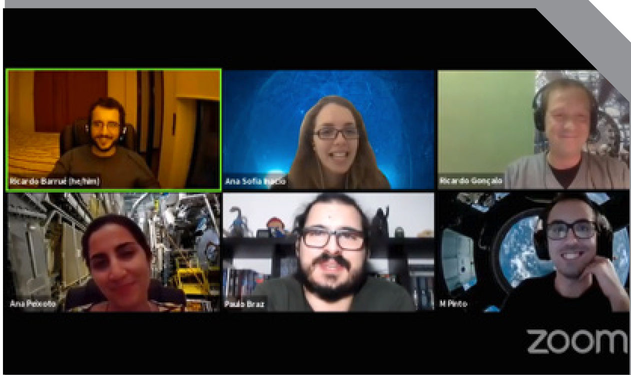
Há luz, uma fábrica e um enorme anel no futuro da física na Europa

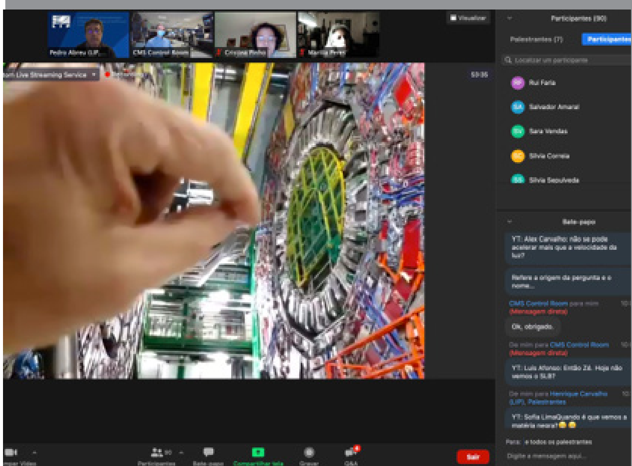
Conselho do CERN apresentou ontem um conjunto de recomendações que deverão guiar o futuro da física de partículas na Europa. O futuro passa por aumentar a intensidade, a precisão e a energia

"Toda a história da física mostra que a coisa mais interessante é aquilo que não se espera"

Publications and printed material

In 2020 the LIP-ECO office published: the LIP Public Report 2019 (online and printed for free distribution); issue nb.17 of the LIP-News Bulletin (online and printed for free distribution); tribute site to Gaspar Barreira; a new flyer on LIP's science for the general public (to be printed in 2021); regular posts on the LIP website news and social media (more than once per week on average for the website news and several per week on facebook and twitter); four issues of the internal digital newsletter cLIP; several items (mainly stationary) to be distributed to the participants of the LIP Internship Programme.





European Researcher's Night

2020 was a good year for the European Researchers Night at LIP, mostly online with live streaming on LIP's youtube channel. Braga took-off at 17:00 with a virtual visit to the ATLAS experiment conducted by PhD student Ana Peixoto in Braga, and with Mariana Velho (Science Communication student from UMinho) and the Brazilian colleague Denis Damazio at CERN. Coimbra took over from 20:00 onwards, with a "Tertúlia" counting on a panel of young researchers from the three nodes of LIP: Ana Peixoto (ATLAS PhD student), Ana Sofia Inácio (SNO+ PhD student), Marco Pinto (young researcher in the SpaceRad group), Paulo Braz (LZ PhD student) and Ricardo Barrué (ATLAS PhD student). The "Tertúlia" was moderated by Ricardo Gonçalo. From 21:30 the NEI went on from Lisbon, with a virtual visit to CMS. The hosts were Pedro Abreu (in Lisbon) and José Carlos Silva and André David (at CERN). Several hundred people attended at least part of the programme, in a night in which many research institutions were online. Henrique Carvalho, from LIP-Minho, has put in place all the technical setup.

LIP's programme for the school community

At LIP a comprehensive programme for the school community has been put in place along the years. Flagship initiatives are IPPOG's International Masterclasses in Particle Physics and the Portuguese Language Teachers Programme at CERN.

IPPOG's International Masterclasses in Particle Physics

The Masterclasses give high-school students the opportunity to become scientists for one day: at research centres and universities in over 50 countries, they analyze real data from particle physics experiments (in particular LHC experiments) and share and discuss their results with scientists at CERN or at Fermilab and with participants in other institutions. LIP is the national coordinator of the Masterclasses in Portugal since they started in 2005. The event is usually held in over a dozen cities all over the country gathering more than 1500 participants per year. In 2020, due to the COVID-19 pandemic, only the first four out of the planned 14 sessions could be held before the start of the first lockdown in Portugal, in March. About 400 students and teachers participated.

CERN Teachers Programme in Portuguese Language

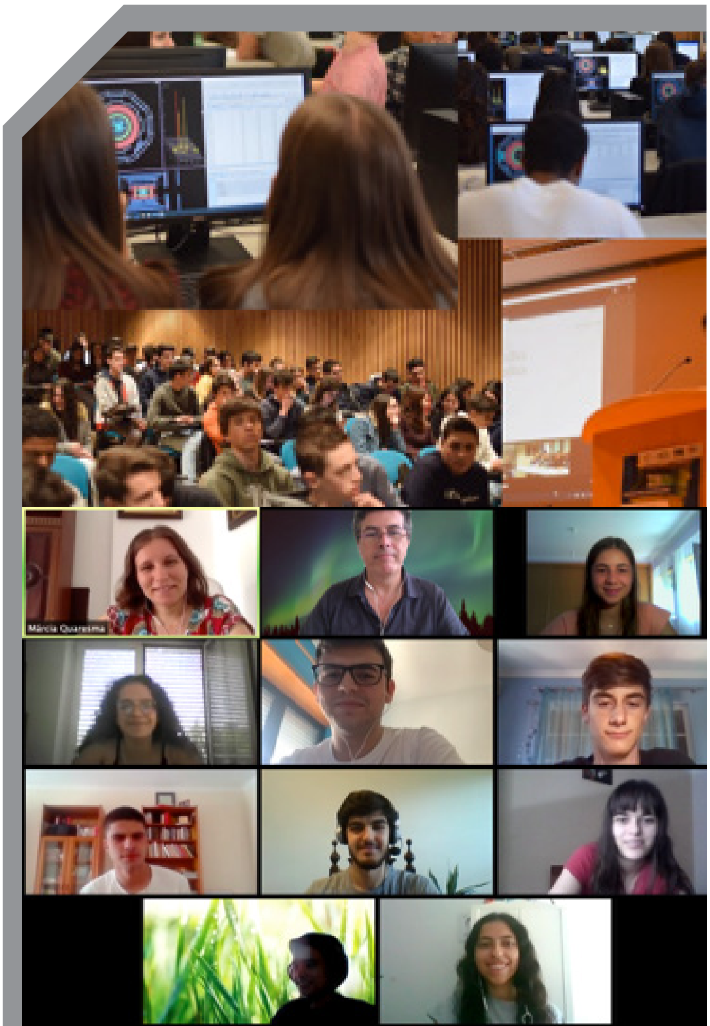
CERN conducts training courses reaching more than 1000 high-school teachers per year. Training program in national languages of member states started in 2006, and the first Portuguese-language training at CERN was held in 2007. Two years later, the program became the first to host teachers from non-member countries with the same language. Over the last decade, more than 700 teachers attended the programme, coordinated by LIP with the support of CERN and Ciência Viva. The 2020 edition had to be postponed to 2021 due to COVID-19.

Summer internships for high-school students

The "Science in the Summer" Ciência Viva internship programme for high-school students took place remotely at LIP, welcoming 10 participants in four LIP research groups. An advantage of online internships is that students from all over the country can participate. The possibility of keeping a remote component next year will be considered.

Seminars in schools

LIP maintained its participation on the CV "Space goes to school" event, with over 17 talks in schools (most of them in remote mode) and the participation of researchers from several LIP groups. In this case, the combination of regular visits to schools with the use of remote communication technologies is a clear advantage for the programme and should be kept in the future, as it allowed for a much wider geographical reach. LIP also visited schools in many other occasions, in a total of over 50 outreach talks by several LIP researchers.



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Glossary

AGN - Active Galactic Nuclei
AMS - Alpha Magnetic Spectrometer (particle physics experiment in the ISS)
AEEF - Alphasat Environment and Effects Facility (ESA)
AHEAD - Integrated Activities for the High Energy Astrophysics Domain (H2020)
AI - Artificial intelligence
Alphasat - the largest European telecom satellite (ESA)
AMBER - Apparatus for Meson and Baryon Experimental (CERN)
AMEGO - All-sky Medium Energy Gamma-ray Observatory (NASA)
ANIMEE - Associação Portuguesa das Empresas do Sector Elétrico e Electrónico
ASIC - Application Specific Integrated Circuit
AT - Advanced Training
ATLAS - A Toroidal LHC ApparatuS (general-purpose experiment at the LHC
Auger - Pierre Auger Observatory (Argentina)
BEXUS - Balloon Experiments for University Students
biodata.pt - Portuguese distributed e-infrastructure for biological data
BioISI - Instituto de Biossistemas e Ciências Integrativas
BTL - Barrel Timing Layer (CMS)
BSM - Beyond the Standard Model
CBM - Compressed Baryonic Matter (one of the pillars of FAIR)
CBPF - Brazilian Centre for Research in Physics (Centro Brasileiro de Pesquisas Físicas)
CC - Competence Centre
CCMC - Monitoring and Control Competence Centre (LIP)
CEFITEC - Centre for Physics and Technological Research, NOVA (Centro de Física e Investigação Tecnológica)
CERN- European Laboratory for Particle Physics, Geneva, Switzerland
CFTC - Centre for Theoretical and Computational Physics, FCUL (Centro de Física Teórica e Computacional)
CFTP - Centre for Theoretical Particle Physics, IST (Centro de Física Teórica de Partículas)
CHUC - Coimbra University Hospital Center (Centro Hospitalar e Universitário de Coimbra)
CMS - Compact Muon Solenoid (general-purpose experiment at the LHC)
CNC - Computer Numerical Control (refers to computer controlled machine or tool)
CNES - French Space Agency (Centre National d'Études Spatulas)
CoastNet - Portuguese Coastal Monitoring Network
COMPASS - Common Muon and Proton Apparatus for Structure and spectroscopy (CERN experiment)
COVID-19 - Disease caused by the coronavirus SARS-CoV-2
CPCA - FCT Call for Advanced Computing Projects (2020)
CS -Control System
CTA - Cherenkov Telescope Array
CTN - Nuclear Technology Campus, IST (Campus Tecnológico e Nuclear)
CTTB - Component Technology Test Bed
CV - Agência Ciência Viva
DCS - Detector Control System
DELPHI - Detector with Electron, Photons and Hadron Identification, experiment at LEP (CERN)

DIS - Deep Inelastic scattering
DL - Detectors Laboratory (LIP)
DQM - Data Quality Manager
DUNE - Deep Underground Neutrino Experiment (CERN/FermiLab)
ECAL - Electromagnetic Calorimeter (CMS)
ECO - Education, Communication and Outreach
ECOTOP - Ecology and Conservation of Top Predators group (MARE)
eCRLab - Cosmic Rays Electronics Laboratory (LIP)
EEE - Electronic and Electric Engineering
EFACEC - Portuguese company, operating in the energy and transportation sector
EGI - European Grid Infrastructure
EGI-ACE - European Open Science Cloud implementation project
EOSC - European Open Science Cloud
ERC - European Research Council
ESA - European Space Agency
ESPP - European Strategy for Particle Physics
ESPPU - European Strategy for Particle Physics Update
ESS - European Spallation Source
EU - European Union
EuroCC - H2020 EU project for HPC coordination
EuroHPC - European High Performance Computing Joint Undertaking
eV - electron-Volt (unit of energy; the energy of an electron under 1 Volt; multiples are: keV, MeV, GeV, TeV, PeV, EeV)
EVOLEO - Portuguese company, operating in the electronic engineering sector
FAIR - Facility for Antiproton and Ion Research (GSI)
FARE - Fake News and Real People (ERC project at LIP)
FCC - Future Circular Collider
FCCN - Fundação para o Cálculo Científico Nacional (FCT)
FCT - Foundation for Science and Technology, Portugal (Fundação para a Ciência e a Tecnologia)
FCUL - Faculdade de Ciências, Universidade de Lisboa
Fermilab - Fermi National Accelerator Laboratory, Illinois, USA
FOV - Field of View
FPGA - Field-programmable gate array (integrated circuit)
GBIF - Global Biodiversity Network
GHIPOFG - Portuguese Institute of Oncology (Grupo Hospitalar Instituto Português de Oncologia Francisco Gentil)
GEO - Geostationary orbit
GPU - Graphics processing unit
GRB - Gamma-Ray Burst
GSI - Helmholtz Centre for heavy ion research, in Darmstadt, Germany
H2020 - EC Framework Program for Research & Innovation 2014-2020
HADES - High Acceptance Di-Electron Spectrometer (experiment at GSI)
HEP - High Energy Physics (or Particle Physics)
HiRezBrainPET - Project for Brain imaging by high resolution PET (LIP participation)
HL-LHC - High-Luminosity LHC
Horizon Europe - EC Framework Program for Research & Innovation 2021-2027
HPC - High Performance Computing
HTC - High Throughput Computing
IBEB - Institute for Biophysics and Biomedical

Engineering, FCUL
IBERGRID - Iberian Computing Grid Infrastructure
ICNAS - Institute for Nuclear Sciences Applied to Health (Instituto de Ciências Nucleares Aplicadas à Saúde)
ICT - Information and Communications Technologies
IDPASC - International Doctorate Network on Particle Physics, Astrophysics and Cosmology
INAF - Istituto Nazionale di Astrofisica (Italy)
ILO - Industrial Liaisons Officer
IMEM - Istituto dei Materiali per l'Elettronica e il Magnetismo (Parma, Italy)
INCD - National Infrastructure for Distributed Computing (Infraestrutura Nacional de Computação Distribuída)
INESC - Institute for Systems and Computer Engineering (Instituto de Engenharia de Sistemas e Computadores)
IPC - Industrial Policy Committee
IPPOG - International Particle Physics Outreach Collaboration
ISS - International Space Station
IST - Instituto Superior Técnico, Universidade de Lisboa
ITQB - Instituto de Tecnologia Química e Biológica (NOVA)
JUICE - Jupiter Icy Moons Explorer (ESA)
KT - Knowledge Transfer
LAr - Liquid argon
LEO - Low Earth Orbit
LHC - Large Hadron Collider (at CERN)
LHCb - LHC experiment
LHCC - LHC experiments Committee
LIP - Laboratory for Instrumentation and Particle Physics
LNEC - Laboratório Nacional de Engenharia Civil
LOMaC - Laboratório de Óptica e Materiais Cintilantes (Optics and Scintillating materials lab)
LUX - Large Underground Xenon (dark matter experiment, at SURF)
LZ - Dark Matter experiment at SURF (merge of LUX and ZEPLIN experiments)
MACC - Minho Advanced Computing Centre
MARE - Marine and Environmental Sciences Centre
MFS - MultiFunctional Spectrometer
MSc - 'Master of Science' (M.Sc.) degree
MW - Mechanical Workshop (LIP)
M&O - Maintenance and Operations
NA38 - CERN SPS experiment
NA50 - CERN SPS experiment
NASA - National Aeronautics and Space Administration (USA)
NEI - European Researchers Night (Noite Europeia dos Investigadores)
NEXT - Neutrino Experiment with a Xenon TPC
NOVA - Universidade Nova de Lisboa
NPstrong - Nuclear Physics and strong interactions (LIP)
NREN - National Research and Educational Network
NUC-RIA - Nuclear reactions and Astrophysics experimental group (LIP)
NUSTAR - Nuclear Structure, Astrophysics and Reactions (one of the pillar of FAIR)
O-PGI - Orthogonal Prompt-Gamma Imaging
OR-imaging - Ortogonal Ray imaging
Ortho-CT - Orthogonal Computer Tomography
PANDA - experiment at FAIR, GSI
PCB - Printed Circuit Board
PERIN - Portugal-Europe R&I Network (ANI)
PET - Positron Emission Tomography

PhD - 'Doctor of Philosophy' (Ph.D.) degree
Pheno - Phenomenology group (LIP)
PI - Principal Investigator
PORBIOTA - Portuguese Infrastructure for Information and Research on Biodiversity
ProtoDUNE - Prototype of the DUNE detector, installed at CERN
PPS - Precision Proton Spectrometer
PQCD - Partons and QCD (LIP)
ProtoTera - Association for Proton Therapy and Advanced Technologies for the Prevention and Treatment of Cancer
PT Space - Portuguese Space Agency
QCD - Quantum Chromodynamics
QGP - Quark Gluon Plasma
R3B - Reactions with Relativistic Radioactive Beams (GSI experiment)
RADEM - RADiation hard Electron Monitor for ESA's JUICE mission
RD51 - CERN collaboration of detector R&D
RICH - Ring Imaging Cherenkov detector
RNCA - National Network for Advanced Computing (Rede Nacional de Computação Avançada)
RPC - Resistive Plate Chamber (gaseous detector)
RPC-TOF-FD - RPC TOF Forward Detector (HADES)
RPC-TOF-W - RPC TOF Wall (HADES)
R&D - Research and Development
R&D&I - Research, Development and Innovation
R&I - Research and Innovation
SARS - Severe Acute Respiratory Syndrome
SHiP - Search for Hidden Particles (CERN)
SM - Standard Model (of particle physics)
SND - Scattering and Neutrino Detector (SHiP)
SNO+ - Sudbury Neutrino Observatory, at SNOLAB. SNO+ is the successor of SNO
SNOLAB - Underground science laboratory, Ontario, Canada
SPAC - Social Physics and Complexity (LIP)
SPENVIS - Space Environment Information System (ESA)
SPF - Portuguese Physical Society
SPS - Super Proton Synchrotron STEM - Science, Technology, Engineering and Mathematics
STRATOSPOLCA- BEXUS Stratospheric Polarimetry with Cadmium Telluride Array experiment
SURF - Sanford Underground Research Facility (USA)
SWGO - Southern Wide-field Gamma-ray Observatory
TACC - Texas Advanced Computing Center
TagusLIP - LIP laboratory at the Tagus Park business campus
TDAQ - Trigger and Data Acquisition System
TileCal - ATLAS Tile Calorimeter (ATLAS hadron calorimeter)
TOF - Time-of-Flight
TPC - Time Projection Chamber (detector)
TRISTAN - name of a specific RPC-based detector
UC - Universidade de Coimbra
WLCG - Worldwide LHC Computing Grid
WLS - Wavelength Shifter (referring to optical fibres)
ZEPLIN - Zoned Proportional scintillation in Liquid Noble gases, series of dark matter experiments (UK)

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