annual report

2022/2023

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.

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about

LIP

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

LIP is the reference laboratory for research in particle physics and related technologies in Portugal, and the Portuguese reference partner of CERN. The laboratory is nation-wide, with nodes in Lisbon, Coimbra, and Braga, closely collaborating with the local universities. LIP has about 100 PhD researchers, 40 technical and administrative staff, and permanently hosts over 80 graduate students. Founded in May 1986 to exploit the unique opportunities created by the country's accession to CERN, LIP is an Associate Laboratory since 2001, and was rated as "Excellent" in the latest independent evaluation promoted by FCT.

The three pillars of LIP's mission are:

- Discovery through science: LIP's program in 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, space exploration, information technologies, and big data analytics
- Community development: LIP works to engage science and society and to address societal challenges through science — promoting scientific culture and education, inspiring the younger generations to pursue careers in science and technology, contributing to the qualification of the Portuguese innovation sector, promoting digital competences and technology accessibility.

Under the supervision of FCT, LIP defines the national policy for the participation at CERN, leading particle-physics related science and innovation, ensuring the involvement of the national academic and business communities, promoting advanced training, and sharing knowledge with society. LIP is also a partner of ESA, the GSI research centre in Germany, SNOLAB in Canada, the Pierre Auger Observatory in Argentina, Fermilab and the Sanford Underground Research Facility (SURF) in the USA and represents Portugal in European digital infrastructures and in science and society international forums. 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).

Growing increasingly multidisciplinary, LIP's research includes three main areas:

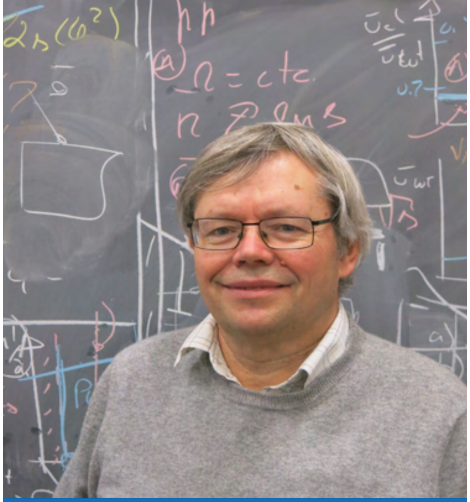
- Particle and astroparticle physics
- Development of new instruments and methods for nuclear and particle physics and of technology applications to health care and space exploration
- Information technologies, scientific computing, and big data analytics.

LIP is engaged in CERN's Large Hadron Collider (LHC), contributing from the very beginning to the two largest LHC experiments, ATLAS and CMS. LIP is also involved in the fixed target programs 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 exploration of the Universe with charged and neutral cosmic rays are among the great challenges of particle physics for the next decades and are part of our agenda. LIP's experimental program is complemented and supported by the high-quality work of LIP's phenomenology and theory research groups.

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

The LIP Computing Groups have extensive knowledge and experience in scientific computing, focusing on grid, cloud, high performance and high throughput computing, artificial intelligence and big data analytics. They have excellent international relations and integration in the main R&D projects and scientific e-infrastructures at European level. LIP co-leads the National Infrastructure for Distributed Computing (INCD), 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, and strongly engaged with community development.



prof.
Mário Pimenta
President

Foreword

Fundamental Science, International Collaborations, Europe, Portugal, LIP

In the turmoil of current times, Fundamental Science is not at the top of the priorities of most governments and citizens. The sense of urgency is everywhere: in the War next door; climate change; environmental and natural catastrophes; energy crises; epidemics and other threats to health; the large fractions of Humanity that are hungry and struggling for survival; the daily rise of prices; the feeling that the future will be worse than the recent past. A century that began with the illusion that it would finally be the time for rationality and global progress is back to fragmentation, disputes, and personal and collective envy in search for local and global powers, the same spirit that led to unthinkable disasters in the first half of the 20th century.

The European Union is sailing through troubled waters, trying to promote short-term political consensus and to mitigate negative societal impacts. Portugal cannot be an exception, of course, but collectively minded, planned, long-term solutions are not usually part of our national traits: "Numa casa onde não há pão, todos ralham, e ninguém tem razão".

In fact the endless debate about whether a country like Portugal should promote public investment in Fundamental Science is back on the horizon.

In the past, in the eighties of the twentieth century, when Portugal became a full member of CERN, the main argument was that such an investment would be a luxury for a small and "poor" country, which would absorb a large fraction of the public investment in science, preventing the development of Applied Science, so necessary to national industry. History has fully demonstrated the opposite. Under the action of José Mariano Gago, the founder of LIP together with Armando Policarpo and Gaspar Barreira, Portugal joined many international scientific organizations and established many bilateral agreements as well. The development of all the Science in Portugal, Fundamental and Applied, was impressive.

Now, forty years later, the argument is more sophisticated: the scientific community in Portugal is already mature enough to find its own independent funding opportunities from international sources, thus avoiding to burden the chronically tight national public budget. Hopefully, as in the past, this point of view is not shared by the general public and the media. Sadly, it is shared by a non-negligible fraction of the scientific community itself, eager to increase the public support to short-term projects, even if at the cost of sacrificing long-term successful programs, and of sowing the seeds of discord.

LIP is, at its core and from the beginning, an institution of Fundamental Science with relevant activities and projects that have a strong and direct impact in society: in information technologies and data science; in biomedical physics and health care; in space applications; in social physics; in education, advanced training and public outreach. Today LIP can be proud of its scientific record, as well as of its activities and societal impact in all these domains, which constitute the common achievement of LIP researchers, technicians, administrative personnel and of all the students that have been trained in the laboratory throughout the years. Today LIP is proud to have been able to go through the hard COVID-19 times, even increasing its activities and the number of Master and PhD students. But LIP is also aware that several aspects of its organization and running must be continuously improved, and that its exposure to the fickle public funding policies in science is too high. We count on, and we are thankful to, our international Advisory Committee, who each year review our activities in depth, recommending trajectory corrections and pointing out opportunities. Their help has been precious, and a heartfelt word of thanks has to be said to Pier Giorgio Innocenti, Christian Fabjan and Gigi Rolandi, who now terminate their already long-term commitment as LIP Advisory Committee members. And also a word of welcome to Werner Riegler, Jorgen D'Hondt, José Miguel Jimenez and Karoline Wiesner, who will now start their work in the committee.

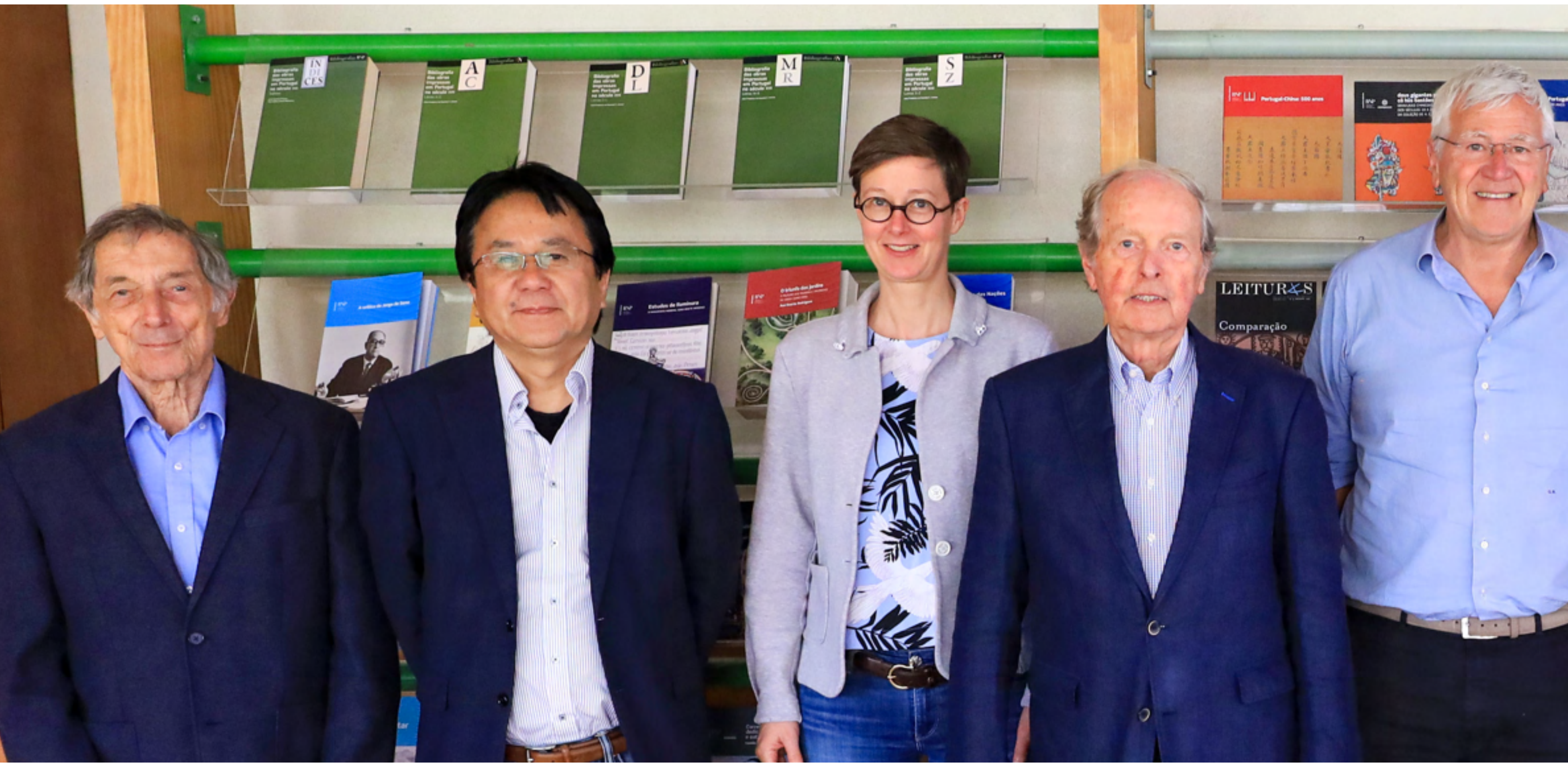
In an ideal world, a long-term consensus between the Research Institutions, the Universities and the Government should have been reached long ago. A consensus which establishes, once and for many years, the organization, the responsibilities, and the duties of all. A consensus that defines the role of each in terms of scientific employment but also the associated core funding. Contract-programs should be established between FCT and the main research institutions that should be followed yearly by external referees, nominated by FCT for extended periods. Evaluation rounds happening every five years, with ever-changing criteria and which are not followed even by the evaluation panels, should end. The evaluation of the institutions that form the backbone of research in Portugal in each scientific domain, with heavy employment responsibilities, cannot be treated as an evaluation of the calls for short-term projects or grants.

Science means cooperation and competition, and Fundamental Science based in peaceful international collaboration is the main vector towards progress and Humanity.

(Mário Pimenta)
Lisbon, March 2023

REPORT FROM THE

International Advisory Committee



LIP's international advisory committee members. From left to right: Pier Giorgio Innocenti, Masahiro Teshima, Karoline Wiesner, Christian W. Fabjan, Luigi Rolandi, Werner Riegler, Eamonn Daly, José Miguel Jimenez, Jorgen D'Hondt. Katia Parodi and Sergio Bertolucci were not able to attend the meeting in person.

The LIP Advisory Committee meeting in 2023 took place primarily as an in-person event on April 27 and 28. The committee would like to thank the LIP management and the LIP community for the excellent preparation of the documents and presentations. Being informed about the activities of the last years, the focus of the meeting was to provide advice on the proposed plans for the upcoming period while addressing the various challenges for the research groups.

Research at LIP is curiosity-driven and enables several possibilities for applications, especially in the field of instrumentation, for the benefit of our health, safety and quality of life in general. LIP researchers are given opportunities to explore new research directions and to seek impactful innovations. Not all exploratory research will and should result in established research groups at LIP. The committee deeply appreciates this vision and congratulates LIP management for establishing and fostering this curiosity-driven research environment. In parallel, the committee recognized the challenges to balance initial exploration efforts with long-term commitments to concrete experiments embedded in international collaborations. Accordingly, it remains important for all actors to continuously clarify and to acknowledge this difference.

LIP's main scientific drivers are aimed to achieve a profound understanding of both the largest cosmological and smallest quantum structures in the universe. On the one hand, LIP studies the fundamental interactions of the smallest building blocks of matter with powerful accelerators, and on the other hand, LIP studies the high-energy phenomena emerging from large structures in the universe with the observations of cosmic rays and possibly dark matter particles.

The proton accelerator complex at CERN is a unique research facility where LIP researchers explore strong interactions with the COMPASS and AMBER experiments, and simultaneously with the ATLAS and CMS experiments at the LHC, LIP studies proton interactions at the highest energies ever established in a laboratory. While fundamental interactions of neutrinos are

being investigated with the SNO+ experiment in Canada, LIP is trying to capture dark matter particles with the LUX-ZEPLIN (LZ) experiment in the USA. In the field of cosmic rays, LIP investigates charged cosmic rays with the world's largest detection array, the Pierre Auger observatory in Argentina, and with the orbiting AMS experiment on the International Space Station. Instrumentation R&D, advanced computing and theoretical research at LIP achieve a remarkable impact to further enable this exploration. The committee is pleased to note that international cooperation is an intrinsic part of LIP's actions and that LIP's scientific achievements are internationally recognized. A testimony are the key leadership positions and impactful responsibilities successfully taken by LIP researchers in international collaborations. In addition to LIP's engagement in running experiments, several exploratory initiatives have been promoted and supported that will enable LIP to participate in future international experiments at the frontier of particle and astroparticle physics, and accordingly to stay on the path of impactful curiosity-driven research.

LIP makes very effective use of the research facilities of CERN, which is rightly considered the most prominent Portuguese laboratory shared in Europe and beyond. Impressive physics results have been achieved with the Run-2 data collected by the ATLAS and CMS experiments, with several leading positions for LIP researchers and key responsibilities in the preparations for the new Run-3 experimental program and detector upgrades to the HL-LHC period. Fostering this involvement of the groups and careers of the most talented researchers is a critical challenge that LIP must address to support this unique high-energy research program as the backbone of LIP's mission. In addition, in the field of strong interactions, LIP made remarkable contributions to the programs COMPASS/AMBER, ISOLDE, R3B@GSI and hadron physics. Looking ahead, it is advised to think ahead of time to further develop a coherent and impactful research program on strong interactions that fits the expertise of LIP and the expected resources. The committee applauds the strong ambition of LIP's pheno group to enhance the potential of current accelerator-based research and to explore opportunities for future collider projects, particularly the FCC program at CERN.

LIP's long-standing involvement in the astroparticle physics programs of the AMS experiment and the Pierre Auger Observatory has established the institute as an international stronghold for the study of cosmic rays, which finds itself now in a leading position to help build the case for the new SWGO facility. The experienced group has properly identified the most impactful research directions for the coming years. If the group can maintain its strength in experience and size, it will be ready to deliver accordingly.

With internationally recognized leadership in the world's best result of the LZ experiment, LIP marks its presence in the search for dark matter particles. Accordingly, the committee supports LIP's vision to participate in the future XLZD project emerging as the unique global future ambition in the field. While the research with the SNO+ experiment is going excellently, it is advisable to timely identify the most impactful physics analysis direction that LIP can take in the DUNE experimental program. The committee was impressed by the very recent results of the SND experiment where the very first neutrinos from the LHC proton collisions were observed. In view of future opportunities with the SHiP proposal, the committee recommends being proactive in planning the overall strategy for decision making in the expanding LIP research portfolio in neutrino and hidden sector physics programs.

LIP's international leadership in RPCs is impressive. Of the emerging international Detector R&D (DRD) collaborations, one will focus on gaseous detectors, including RPCs, and on liquid xenon detectors. This provides LIP with a unique opportunity to consider how it can integrate into this forward-looking program with a coherent research plan for both RPCs, other gaseous detectors and liquid xenon. The groups focusing on particle detector applications are prolific and have attractive hands-on programs for training numerous students. The strength of these programs is an excellent synergy between the generic detector R&D, the targeted applications and the available experimental facilities at LIP. It is therefore important to develop and monitor a coherent and balanced strategy, taking into account a high potential for adequate funding and a high potential for impact and perspectives for early career researchers.

The LIP groups working on astrophysics and space physics are making good progress and have laid foundations for some very interesting future work. LIP's space gamma-ray detector technology could soon see embarkation on NASA and ESA missions. The LIP space radiation group is involved in development of instrumentation for two ESA interplanetary missions and the unique data exploitation has been started.

LIP also continues a broad portfolio of frontier research activities aimed at health and biomedical applications, featuring advanced instrumentation and micro/macroscopic modeling for dosimetry, diagnostic imaging and assessment/verification of treatment efficacy. Important initial results and third party funding could be secured in most of these endeavors. To maintain a competitive program, it is important to develop a strategy to enable impactful contributions taking into account the availability of local infrastructures, the established international networking with cutting edge institutions and exploring collaboration opportunities with the several proton therapy centers currently planned in Spain.

LIP's advanced computing efforts are intertwined with numerous European initiatives and feature on the Portuguese roadmap of research infrastructures. The committee is of the opinion that the impact of LIP's investments and their expertise are aspects that cannot be missed when establishing a national center for high-performance computing. The recent ERC-supported project on social physics and complexity embedded in LIP is a first testimony to the attractiveness of LIP's advanced computing to serve as an important catalyst for multidisciplinary research.

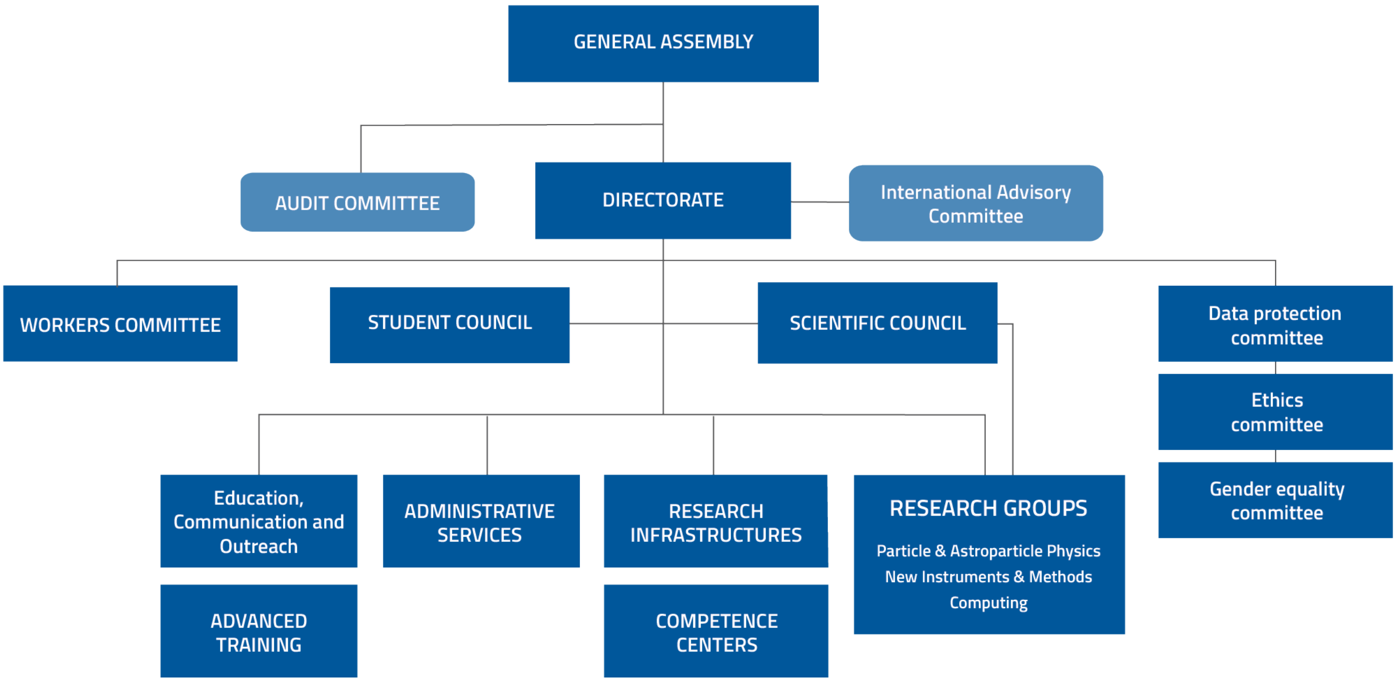
The excellent workshops and laboratories have the appropriate size and competences to respond to the early needs in prototyping and demonstrators, and rely on a very motivated and active team of experts to innovate instrumentation. In addition, the local laboratories with focus on optics, scintillating materials and electronics are exemplary facilities to deliver LIP's detector responsibilities to concrete international experiments. The transversal competence centers aim to leverage knowledge across research groups and to enable optimal training of early stage researchers, as well as to provide opportunities to connect and collaborate with external experts on the subject in order to integrate innovation from their field.

LIP continues to educate a large number of students with excellent training programs. In the field of science communication and outreach, the committee recognizes that LIP excels nationally and internationally in implementing a very clear strategy. Integrating an effort to analyze the impact of the activities could help direct limited resources to the most impactful actions.

The incoming and remaining members of the committee are impressed by the tireless involvement of the three outgoing members of the committee, namely C.W. Fabjan, P.G. Innocenti and L. Rolandi. They have had a tremendous impact on the wonderful evolution of LIP in the international landscape of particle physics and related instrumentation which has been acknowledged and praised by committee members and the LIP community at large. It was with the utmost gratitude that this moment was marked at their last meeting of the LIP Advisory Committee.

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.



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 the Electrical and Electronics Business Association (ANIMEE).

International Advisory Committee

An External Advisory Committee provides strategic advice to the Laboratory. The Committee is formed by worldwide recognized experts in the areas of activity of LIP and holds regular meetings with the directors and the group leaders. In 2021, the members of the IAC were: Christian W. Fabjan, Eamonn Daly, Katia Parodi, Luigi Rolandi, Masahiro Teshima, Pier Giorgio Innocenti, Sergio Bertolucci. In 2022 the following new members joined the IAC: Jorgen D'Hondt, José Miguel Jimenez, Karoline Wiesner and Werner Riegler.

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 LIP community. At present the national directorate is formed by Mário Pimenta (president), Isabel Lopes, Nuno Castro, Patrícia Gonçalves and Ricardo Gonçalo.

Scientific Council

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

Workers Committee

The LIP Workers' Council has been legally constituted in 2021 as LIP workers' interlocutor for the institution's management. Its effective members for the mandate from 2021 to 2024 are Américo Pereira, Rui Alves (coordinator) and Sofia Andringa.

Student Council

LIP's Student Council promotes the communication between students from different LIP nodes, encouraging the exchange of ideas, interests and mutual aid between students. It also suggests and assists in the preparation of advanced training activities.

Reaserch groups

The basic scientific organizational units of LIP are the research groups, which are organized in eight Research Lines gathered in three Research Areas: particle and astroparticle physics; development of new instruments and methods; computing. The research groups have the support of LIP's research infrastructures and competence centres. The science and society teams aim at boosting and organizing LIP' engagement with society in many different ways.

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, including Grant's office (pre-award); Accounting and Financial Management.

Selected news of the year 2022

JANUARY

- LIP researcher Joana Gonçalves de Sá was on the Expresso newspaper podcast "Perguntar Não Ofende"
- The LIP Distributed Computing and Digital Infrastructures Group will participate in four new European projects.
- Maria Ramos, from LIP-Minho, defended her PhD thesis developed within the LIP Phenomenology Group. The School of Sciences of U.Minho later considered it the best thesis of the year.

FEBRUARY

- Eduardo Ferreira, from the LIP NPstrong Group, defended his MSc thesis in November. The paper based on his work was published in Phys Rev D and picked as Editors suggestion.
- LIP and IAstro celebrated together the International Day of Women and Girls in Science with the webinar on multimessenger astronomy
- The Masterclasses in Particle Physics in Portugal started in Braga, returning to the face-to-face format.

MAY

- LIP's participation in European computing projects highlighted at Ciência 2022.
- 36th anniversary of LIP was marked by the inaugural Masterclass of the Pierre Auger Observatory and a session about the 10 years of the Higgs boson and the future of particle physics.
- The LouMu muon telescope was transported to the Lousal mine and started to collect data.

JUNE

- LIP was part of the team that have launched a stratospheric balloon to measure radiation at altitude.
- LIP researcher Sofia Andringa was in the Antena 1 broadcast "90 segundos de ciência".
- The third edition of Data Science School and Symposium, organized by LIP, took place in Coimbra.

SEPTEMBER

- The European Research Council has announced the award of Proof of Concept funding to LIP researcher Joana Gonçalves de Sá.
- Portuguese Language Teachers School at CERN, co-organized by LIP.
- The Minister of Science, Elvira Fortunato, the vice-president of FCT visited CERN.
- Paulo Brás, researcher in the LIP, is the new Data Analysis Coordinator of the LZ experiment
- HADES Collaboration meeting in Coimbra.

OCTOBER

- LIP attended to the European Researchers Night in Braga, Coimbra and Lisbon.
- LIP led measurement in ISOLDE at CERN.
- LIP was present at the XVI RPC Workshop, held at CERN, with six oral contributions and one poster.
- IBERGRID took place at Universidade do Algarve for a four days meeting.
- ATLAS Week, in Lisbon, had two public outreach sessions.

MARCH

- The signing ceremony of Brazil's accession agreement as an Associate Member State of CERN, with the presence of the Minister of Science, Technology and Innovation (MCTI) of Brazil, Marcos Pontes

APRIL

- A new RPC-based detector built at LIP is now part of the R3B experimental setup at the GSI.
- The TGF Monitor experiment, led by the LIP i-Astro group, has been selected to be launched in the new reusable vehicle of ESA.
- LHC restarts after a stop of more than three years for maintenance and upgrades.
- CMS-LIP group appeared in a Physics Briefing.

JULY

- Jonathan Hollar, researcher in LIP, has been appointed coordinator of the PPS of the CMS experiment.
- First scientific results from LZ, in wich LIP is a founding member, were presented
- The LIP Summer internships 2022 took place in the three nodes of the laboratory.
- Coimbra hosted Jornadas do LIP and the Student Workshop.

AUGUST

- LIP hosted internships within the program Ciência Viva in the Laboratory.

NOVEMBER

- Maria Gabriela Oliveira, a research initiation student at LIP Minho, has been awarded a Gulbenkian New Talents Grant
- Exhibition: LIP in "What is UC research about?"
- LIP at the 2022 RNCA Meeting
- Pedro Abreu (LIP/IST) received the Ciência Viva Education Prize 2022

DECEMBER

- First ProtoTera PhD Student Workshop, held in Coimbra
- Catarina Felgueiras e Pedro Pereira awarded with Uminho Award for Initiation in Scientific Research
- Hardware designed and built at LIP installed at ProtoDUNE-II

Organized events and Awards of 2022

2022-10-10 / 2022-10-14
“ATLAS WEEK”
Lisbon, Portugal

2022-10-10 / 2022-10-14
“IBERGRID 2022”
Lisbon, Portugal

2022-07-4
“Particle Fever, public session and debate”
IST, Coimbra, Portugal

2022-09-23
“Baryons, from the lab to neutron stars”
University of Coimbra, Portugal

Awards to LIP Members

Eduardo Ferreira

“McCartor Fellowship Award 2022”, 2022-09-09

Gabriela Oliveira

Gulbenkian “Novos Talentos” grant, 2022-11-04

Pedro Abreu

“Prémio Ciência Viva Educação 2022”, 2022-11-24

Pedro Mendes Pereira

“UMinho Award for Initiation in Scientific Research 2022”, 2022-12-13

Catarina Felgueiras

“UMinho Award for Initiation in Scientific Research 2022”, 2022-12-13

Maria Ramos

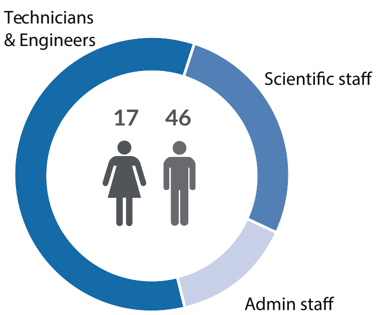
“School of Sciences of UMinho best 2022 PhD thesis award“, 2022-12-31

LIP

in numbers

Human Resources

STAFF



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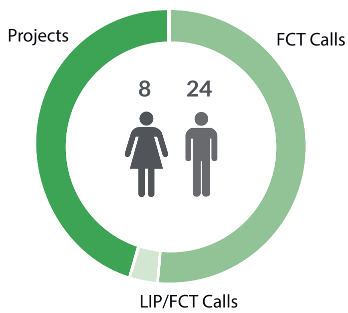
63
TOTAL

	Women	Men
Technicians/ Engineers	4	33
Scientific staff	5	12
Admin staff	8	1

FIXED-TERM RESEARCHERS



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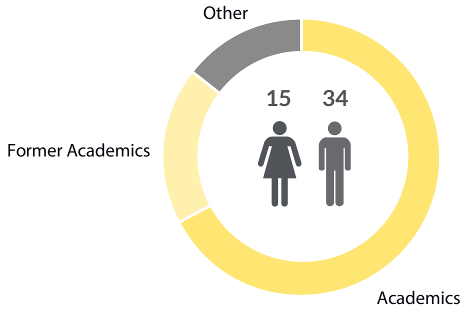
32
TOTAL

	Women	Men
Projects	5	11
FCT Calls	3	12
LIP/ FCT Calls	0	1

UNPAID



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49
TOTAL

	Women	Men
Academics	10	23
Former Academics	4	5
Other	1	6

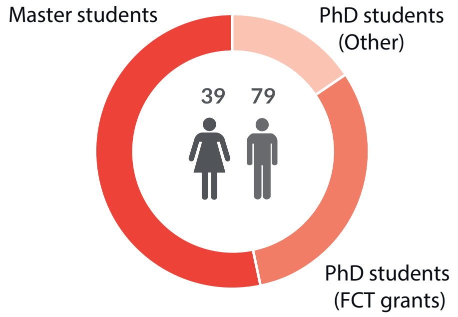
TOTAL 262

Women: 79 Men: 183

PHD RESEARCHERS 96

Women: 28 Men: 68

STUDENTS



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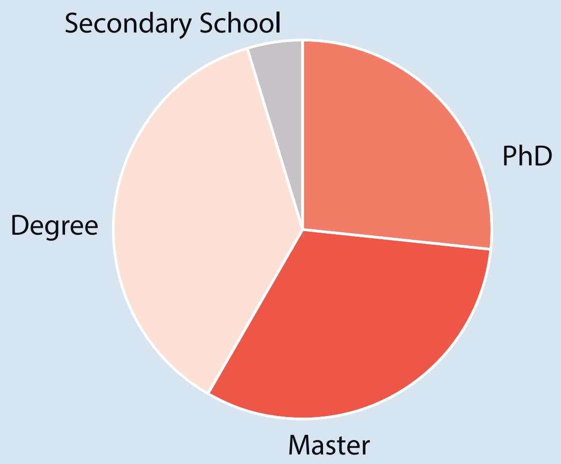
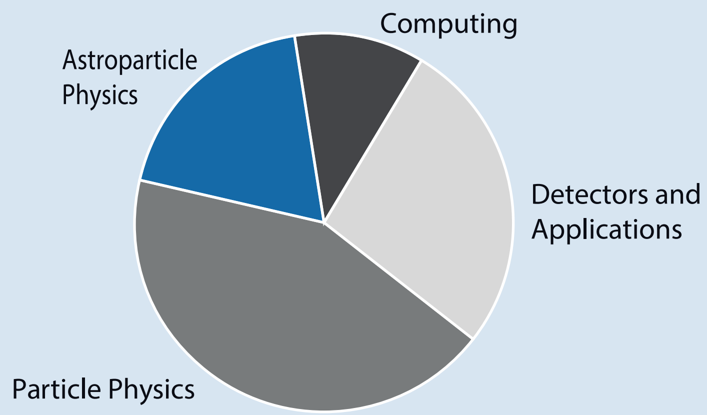
118
TOTAL

Master students	20	44
PhD students FCT grants	15	22
PhD students (Other)	4	13

DISTRIBUTION BY ACADEMIC QUALIFICATION

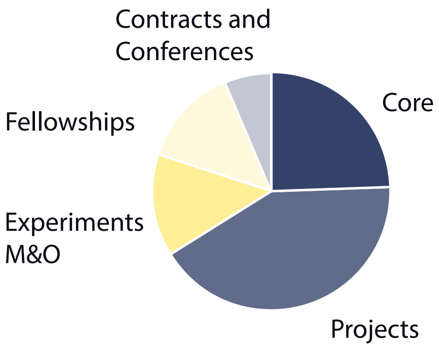


DISTRIBUTION BY RESEARCH AREA



Finances

GENERAL FUNDING



1.6M
CORE FUNDING

2.7M
PROJECT-BASED

0.9M
FELLOWSHIPS

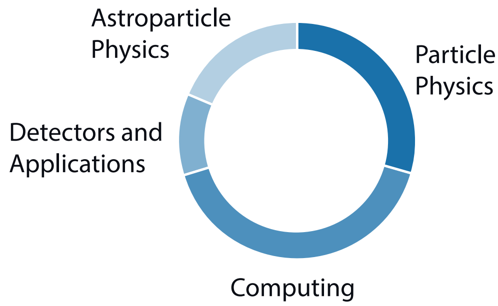
0.9M
EXPERIMENTS M&O

0.4M
CONTRACTS AND CONFERENCES

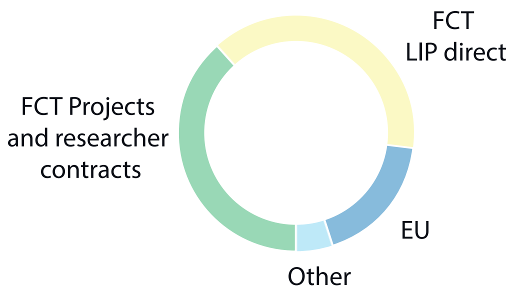
TOTAL
6.5M €

PROJECT AND CONTRACT-BASED FUNDING

BY RESEARCH AREA

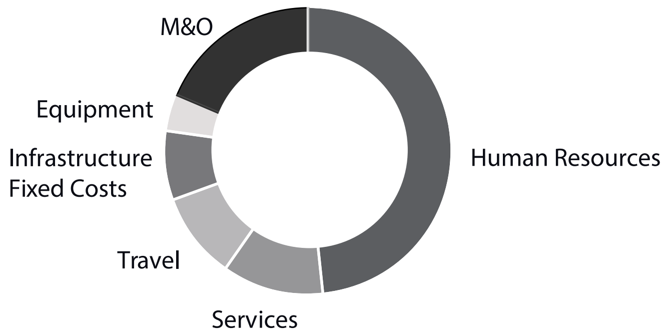


BY ORIGIN



TOTAL
2.7M €

COSTS



HUMAN RESOURCES

STAFF 2.2M

FIXED-TERM RESEARCHERS 1.8M

SERVICES AND OTHER EXPENSES

0.5M

TRAVEL

0.5M

EXPERIMENTS M&O

0.9M

INFRASTRUCTURE FIXED COSTS

0.4M

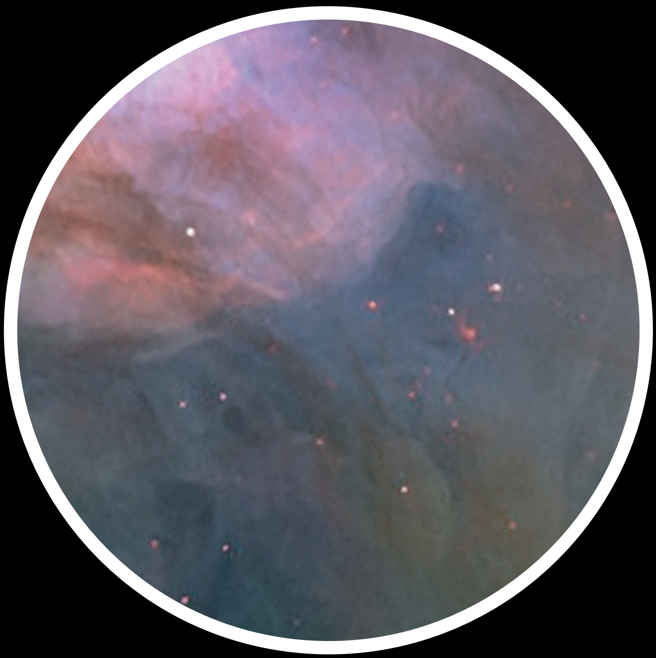
EQUIPMENT

0.2M

Scientific output 2022

	Particle Physics	Astroparticle Physics
Papers in refereed journals	180	47
Proceedings Preprints and Notes	41	32
Books, Reports and Proposals	0	2
Presentations in International Conferences	40	13
Other Presentations	72	48
Master Theses	9	6
PhD Theses	1	3

Detectors and Applications	Computing	TOTAL
27	4	252
15	19	104
1	5	8
24	26	99
49	35	190
10	2	26
0	0	4



Experimental particle
and **astroparticle**
physics

Development of
new instruments
and **methods**

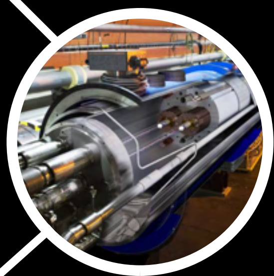
Computing

research at

LIP

Experimental particle and astroparticle physics

Development of new instruments and methods

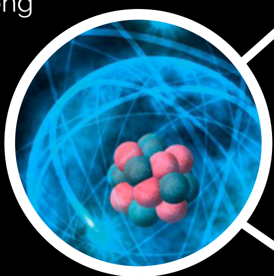


LHC experiments and phenomenology

- ATLAS
- CMS
- Pheno
- FCC

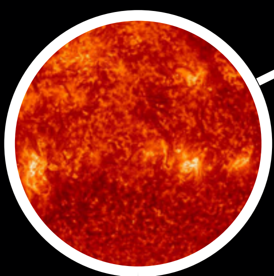
Structure of matter

- pQCD
- HADES
- NUC-RIA
- NPstrong



Cosmic rays

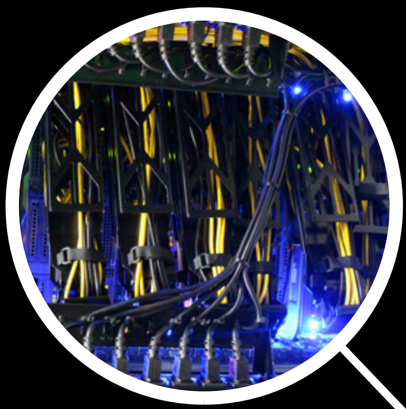
- AMS
- Auger
- SWGO

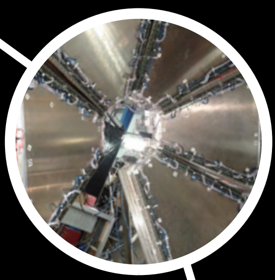


Dark matter and neutrinos

- DARK MATTER
- NEUTRINO
- SHiP/ SND@LHC

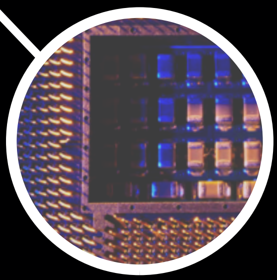
Computing





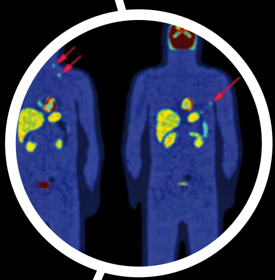
Detectors for particle and nuclear physics

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



Scientific computing

- GRID - Distributed Computing and Digital Infrastructures
- SPAC - Social Physics and Complexity



Health and biomedical applications

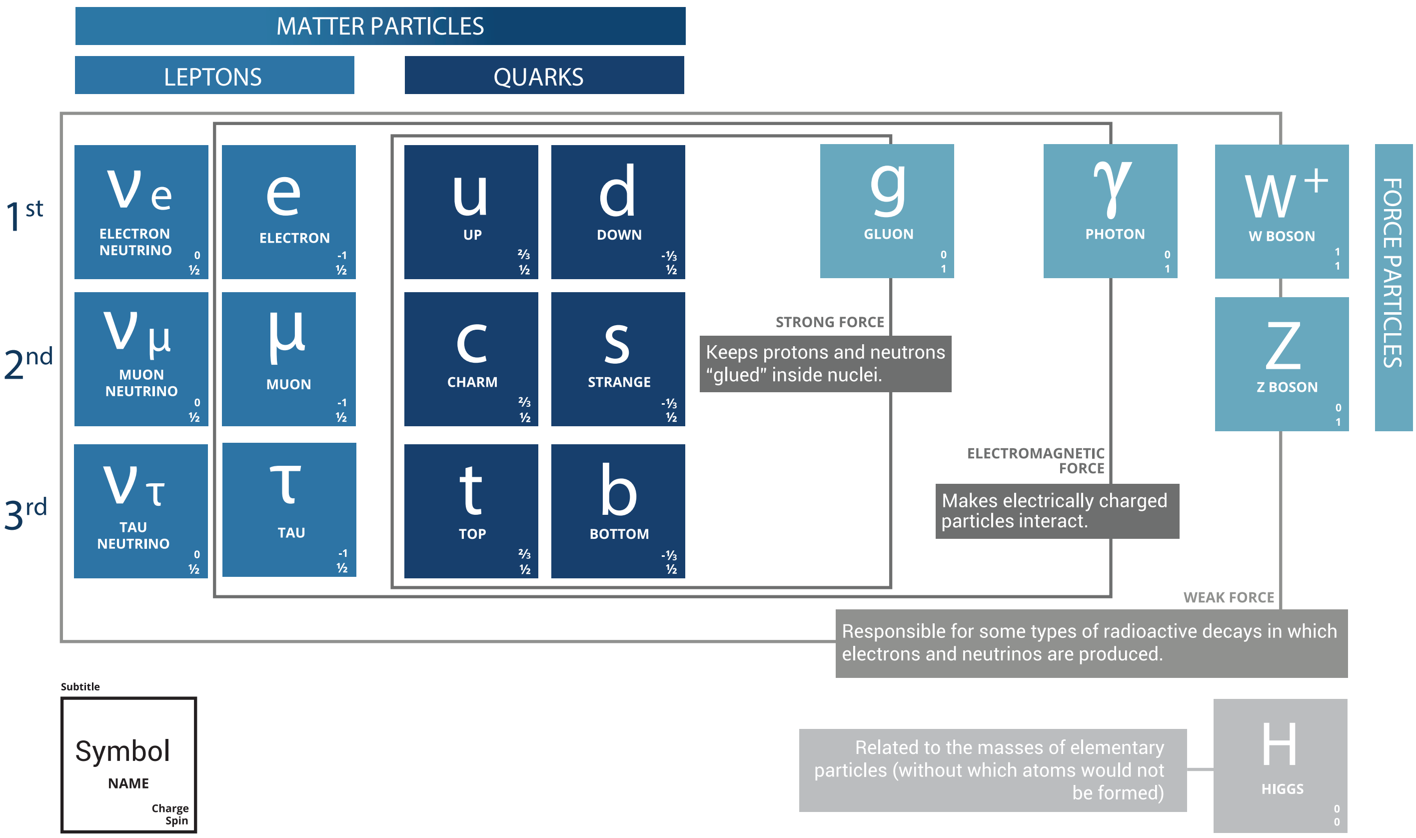
- RPC-PET
- Proton Therapy
- OR Imaging
- RADART

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 ($E = mc^2$). 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 endeavor, contributing from the very beginning to the two largest LHC experiments, ATLAS, and CMS. With these fantastic scientific instruments, we are studying Nature in many ways, from deepening our understanding of the Higgs boson to searching for new physics or recreating the conditions that existed just after the big bang. At the same time, we are very actively improving our experiments, to respond to future challenges of running at higher LHC luminosities, and we are starting to prepare the far-future with LIP's recent involvement in the Future Circular Collider (FCC) feasibility study. LIP's Phenomenology group conducts research bridging theory and experiment. Its research, while independent, is centered in areas in which LIP has active experimental activities. Its purpose is to strengthen impact through the provision of excellent directed phenomenological research.

We still have a lot to discover 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 in the final runs of the COMPASS experiment, and in preparing its successor fixed-target experiment AMBER. 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.

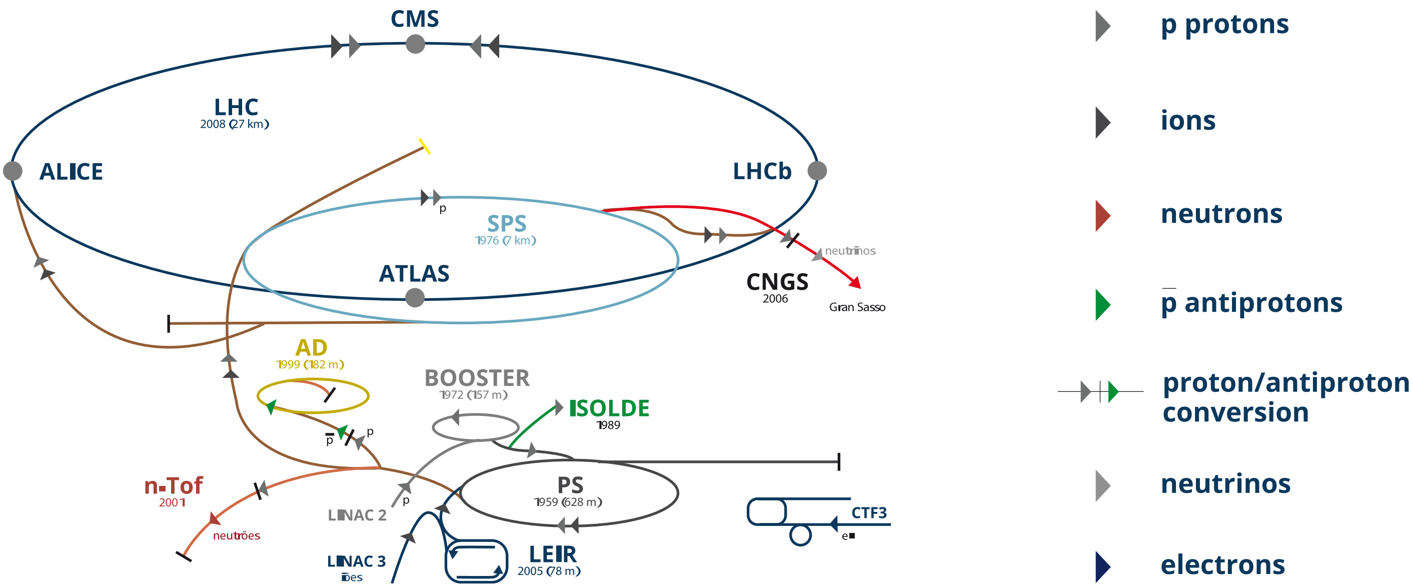
Experimental particle physics is conducted in ever more powerful accelerators, but also in astroparticle physics experiments, detecting particles that come to us from the cosmos. The quest for dark matter, a deeper understanding of the elusive neutrinos, or the origin and nature of charged and neutral 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. Its first step will be the installation of its neutrino detector (SND) at the LHC already in the run staring in 2022 (SND@LHC), providing first observations of collider neutrinos.

LHC experiments and phenomenology

Physics at the energy frontier

In 2022, the Run 3 of the LHC took off and the experiments started taking data at 13.6 TeV after a three-years period of maintenance and upgrades. In parallel, analyses using the full Run 2 (2015-2018) data set are still being concluded, as well as the preparation of both accelerator and experiment for the high luminosity phase HL-LHC scheduled to start in 2029. The new detectors and upgrades will be installed during the long shutdown from 2025 to 2027 and HL-LHC commissioning will start at the end of 2027. LIP is also very much engaged in the most recent LHC experiment SND@LHC, which started taking data from the start of Run 3 to exploit the LHC potential as a neutrino factory. The LIP Phenomenology group is now a large team with consolidated research programmes in both QCD and new physics searches. The successful synergies with the Simulation and Big Data Competence Centre continue as, increasingly, machine and deep learning techniques become ubiquitous in our work. Last but not least, we are also preparing the far-future. The LIP FCC group was created in late 2021 to contribute to the ongoing Future Circular Collider (FCC) feasibility study. The group starts from a core of members from LIP's ATLAS, CMS and Pheno groups, who were involved in the production of the FCC Conceptual Design Review.



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

Higgs and Top physics have for long been a particular specialty of LIP's ATLAS, CMS and Phenomenology groups. The experimental teams first focused 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). In 2022, the LIP ATLAS team pursued its involvement in HH associated production studies with the Run 2 data set. Given the relevance of the ttc background in this studies, the team is now also contributing to the measurement of ttc production. Both the ATLAS and CMS teams also focused on the Higgs as a window to physics beyond the SM. The LIP-CMS group has been leading the search for the rare Higgs boson pair (HH) production process using Machine Learning tools. This process gives access to the Higgs self-coupling parameters, and new physics processes can significantly alter the expected production mechanism. The Run 2 results have been published in 2022. Projections of the expected sensitivity were updated for different HL-LHC conditions.

The LHC is a top quark factory, providing the best opportunity for detailed measurements of the heaviest of fundamental particles. The huge mass of the top quark makes it a likely window to observe subtle effects of physics beyond the SM.The LIP CMS team led the data analysis and publication of the first Run 2 measurement of the top-quark pair production cross section with the top decaying to tau leptons. Studies are continuing to assess the lepton flavour universality in the leptonic decays of the W boson. The group is also pursuing an analysis of top-quark pair production (and tau-, W- and Z-pair production) 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 LIP CMS team has since long a leading role in the PPS detector, which collected over 100 fb-1 of data in Run 2. The higher luminosity and the upgraded detector open new possibilities for Run 3. The LIP ATLAS team is leading and actively contributing to the effective field theory interpretation of different precision measurements in the top quark sector, aiming to constrain the possible forms of 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 anomalies in data.

Both the ATLAS and CMS LIP teams were busy concluding search analyses using the full Run 2 data set in variety of models and channels: exotic heavy quarks, whose existence could account for the unexpectedly low value of the Higgs mass; forbidden or rare quark flavor changes; final states with multiple bosons and/or Higgs bosons; single-top final states and other events with a large missing energy, which is a signature for particles escaping detection and may also indicate the presence of a dark matter particle — which is also searched for in associated production with a Higgs boson; supersymmetry, according to which each known particle is expected to have a supersymmetric partner with different spin and could include the perfect candidate to explain dark matter. However, showing that this is realized in Nature has so far proved to be a difficult task. After the analyses, other tasks include the interpretation within different possible models or the combination of different contributing channels. Several searches were published in 2022, and/or their results have been presented in the main international conferences in the field. Another focus was the development of approaches that maximise the physics information extracted from Run 3 data. Examples are topology-based approaches and heavy resonance searches using sophisticated anomaly detection methods.

The work of the two experimental teams is well matched to the expertise in the Phenomenology group, whose core portfolio of activities includes, among other, top-quark, Higgs, and BSM physics. The Phenomenology group has established a close synergy with the Competence Centre on Simulation and Big Data, with studies addressing in particular putative new physics signals in collider searches. The effort to explore physics opportunities in future colliders contributed significantly to the creation of a dedicated FCC group at LIP.

Secrets of the strong force

Hadrons containing one of the heaviest quarks (c, b, t, usually referred to as heavy flavors) are a likely window to observe subtle effects of physics beyond the SM. The interest is reinforced by the so-called flavor anomalies, consisting of different hints of deviation of SM's expected flavor universality, and by the large, accumulated data sets. The LIP CMS group is keeping a focus on b–›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–›μμ. Another important decay realizing the b–›sll transition is B–›K*μμ. The group carried out the analyses of the angular observables and rates with the full Run 2 data. CMS internal review of the results is ongoing. Involvement of LIP internship students contributed to extensions of the work.

The LIP CMS group is bringing its unique expertise on B physics into the heavy-ion realm. The observation of B meson signals in heavy ion collisions, achieved for the first time by CMS, provides novel probes of the QGP. This work is pursued in collaboration with MIT. The measurement of the nuclear modification factors was developed and entered CMS internal review. The measurement of B mesons production cross-sections at 5 TeV pp collisions is ongoing. In fact, 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 LIP ATLAS team is also involved in QGP studies, focusing on the use of hadronic jets initiated by heavy quarks, and has been developing b-tagging algorithms adapted to this very special environment.

Again, the work of the two experimental teams is very well matched to the expertise in the Phenomenology group. The scope of the group's QCD work has expanded over the years, encompassing at present heavy-ion phenomenology, forward physics, precision collider predictions, and quarkonia studies. The group has accumulated extensive expertise in the development of event-generators and has pioneered studies for extracting the time evolution of QGP, including its formation stages, through analysis of jet properties. Phenomenological studies of quarkonia, to better understand the mechanisms of hadron formation in QCD, have also been pursued in collaboration between the CMS and Phenomenology groups.

Tools of the trade - Detector Upgrades

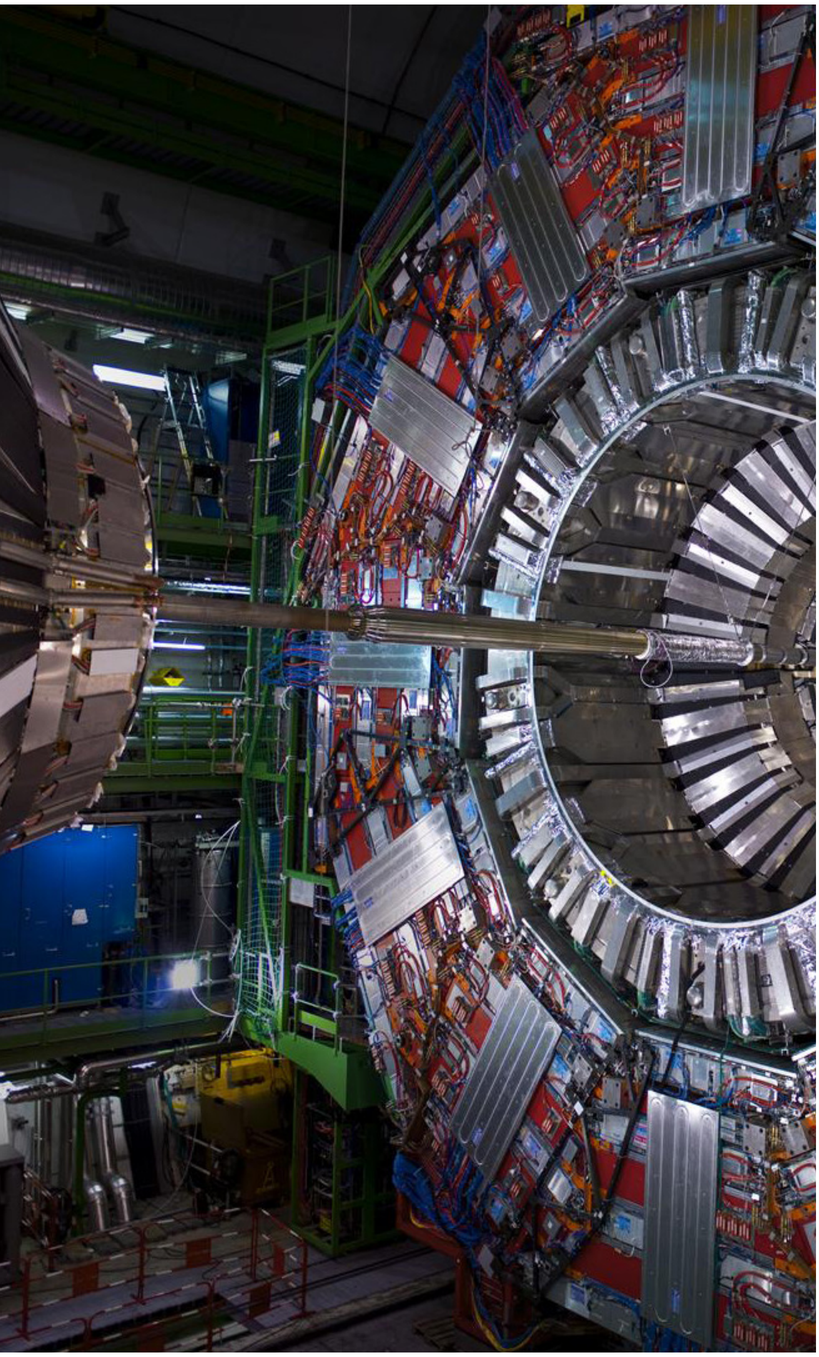
In 2022, the ATLAS and CMS teams at LIP got ready for the start of Run 3 and operated their detectors and tools, performing expert shifts, data quality monitoring, calibrations, and other operation activities. In parallel, they performed detector development activities in view of future upgrades. Also, both teams contribute to the LHC Grid computing maintenance and operations. The CMS group has been mainly involved in the preparation of the PPS and the ECAL detectors. The ATLAS team coordinates the maintenance, control system, operation, and calibration of the TileCal calorimeter, forward detectors, and parts of the trigger system.

In the High-Luminosity phase of the LHC physics program starting in 2029, the accelerator will provide an additional integrated luminosity of 3000 fb-1 over 10 years of operation. The LIP CMS group participates in the construction of a new Timing Detector and in the upgrade of the barrel and endcap calorimeters. The LIP group is responsible for the design and construction of the readout system of the Barrel Timing Layer (BTL), including a high-performance TOF ASIC for time measurement. In collaboration with industry, LIP provides a high-performance ADC ASIC for the ECAL front-end electronics resistant to radiation. The CMS upgrade includes also the complete replacement of the end-cap calorimeters with a new high-granularity sampling calorimeter. LIP collaborates with industry to supply a high-current low voltage regulator (LVR) resistant to radiation for the High-Granularity Calorimeter (HGCAL) front-end system.

The LIP ATLAS team 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. The team is also involved in the High Granularity Timing Detector (HGTD), with responsibilities in the DCS system and front-end ASIC tests.

Looking into the future

Following the 2020 update of the European Particle Physics Strategy (EPPS), a global collaboration was established, dedicated to producing a feasibility study for a Future Circular Collider (FCC) facility located in Geneva. If approved, this facility will represent the future high-energy frontier in accelerator physics and will succeed the High Luminosity LHC from around 2040 onwards. It will include an e+e-collider (FCC-ee) devoted to a broad physics programme with highlights in Higgs, top and electroweak precision measurements. This will later be replaced by a hadron machine (FCC-hh), which will share most of the infrastructure of the previous collider and repeat the virtuous cycle represented by LEP and the LHC (which, in sequence, used in same tunnel and accelerator chain). It will enhance the current energy frontier by an order of magnitude, allowing a future generation of physicists to explore the limits of the SM and possibly reach beyond, to a more fundamental theory.



The FCC group at LIP is currently focused on contributing to the ongoing feasibility study for the Future Circular Collider (FCC). More generally, it aggregates research interests on future collider-based HEP projects and facilities, to boost the long-term participation of LIP in the future of particle physics. The group grew from a core of members from the ATLAS, CMS and Phenomenology groups at LIP, who were involved in the production of the FCC Conceptual Design Review, one of the inputs to the most recent update of the European Strategy for Particle Physics. In 2022, activity grew along a few lines of development: R&D on new radiation-hard scintillators and detector simulation, an analysis feasibility study, and theoretical calculations of Standard Model parameters relevant for the FCC-ee programme.

Neutrinos at the LHC

LIP is a founding member of the Scattering and Neutrino Detector at the LHC, SND@LHC, which is taking data from the start of Run 3 to exploit the LHC potential as a neutrino factory. In 2022 detector installation in the TI18 tunnel was accomplished in time for the LHC collisions in Spring. Efficient operation and accumulation of first physics data has followed. The activities of the LIP group spanned commissioning, data taking, validation, analysis, and upgrade studies, in a close collaboration between the Lisbon and Coimbra nodes of LIP.

// CONTACTS

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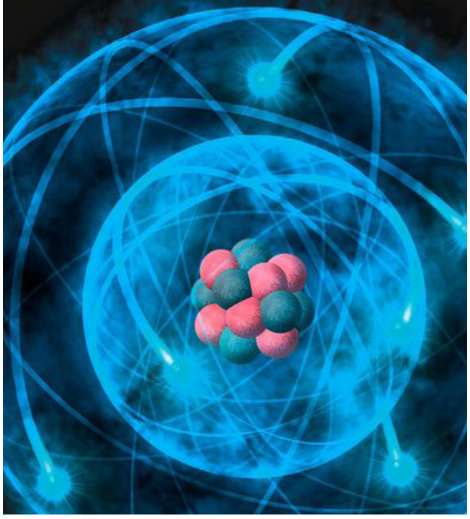


Structure of matter

Looking inside hadronic matter

We still have a lot to discover about the ways in which quarks and gluons work together to form the particles we observe, and that's the focus of LIP's structure of matter research line. The Partons and QCD group is currently involved in studying hadron structure in the final runs the COMPASS experiment, and in preparing its successor 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, the 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 is now focused on the completion of COMPASS and in the starting AMBER experiment. 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. The experiment used beams from CERN's SPS accelerator, colliding high intensity muon or hadron beams with a polarized target at a temperature only 0.1 degree above absolute zero. The target is followed by a two-stage spectrometer that observes the particles resulting from the collision. The successor experiment AMBER inherits several components of COMPASS.

The COMPASS experiment concluded its data-taking in November 2022 with deep inelastic scattering (DIS) of a muon beam off a transversely polarized deuteron target and now fully focuses on data analysis. The LIP group as special responsibility in Drell-Yan — high-mass lepton-pair production in a hadron-hadron collision, a powerful tool for probing the partonic structures of hadrons — and charmonium. The results on the J/psi cross-section tungsten-to-aluminium ratio as a function of dimuon transverse momentum and Feynman-x variables were released and presented in 2022.

In 2022 the LIP team ensured the permanent presence of an expert supporting the Detector Control System (DCS), who was also COMPASS Run co-coordinator 2022 and member of the AMBER and COMPASS technical boards. The modification of the DCS to the AMBER conditions is being done by the group.

The AMBER experiment officially started its data-taking phase in 2022, with two short beam tests. The goals were to tune the proton beam and collect small data samples at varying beam momenta, while testing the new Unified Tracking Stations (UTS) and the new triggerless data acquisition mode. The preliminary analysis allowed to validate the procedures and confirmed the beam characteristics, essential steps for the antiproton production cross-section measurement that will take place in 2023.

The AMBER Memorandum-of-Understanding is ready to be signed in the course of 2023. The pilot Run for the proton radius measurement of AMBER will happen in the second half of 2023. The main responsibilities of the group in AMBER are on the Drell-Yan topic, namely on physics simulations that include the new detectors and setup modifications, and in developing new analyses approaches for beam particle identification using CEDARs (Cherenkov Differential Counter with Achromatic Ring Focus).

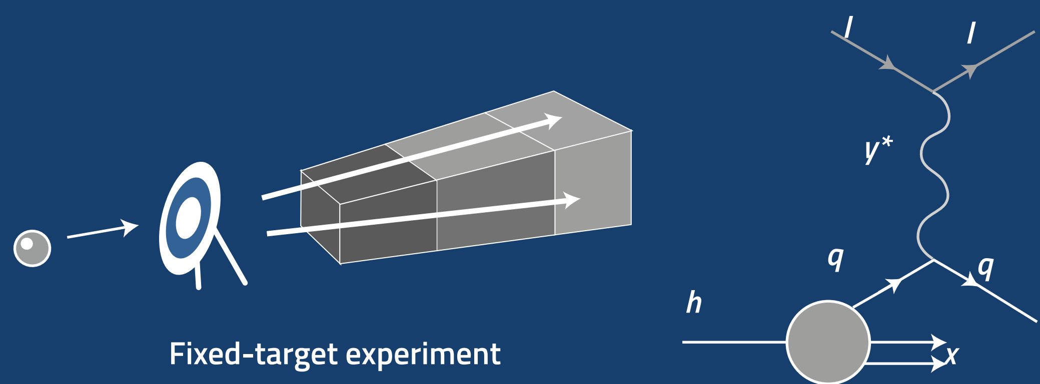
Stars and Nuclei

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 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 and Instrumentation Group (NUC-RIA) is part of NUSTAR's R3B (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 where sits the HADES experiment, in which LIP is involved. Scientists want to find out how matter changes at such densities. The LIP HADES group designed, built, and operates an essential component of the spectrometer, the 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).

The group extended TOF measurements to the forward region of the detector (closer to the beam direction) with the new RPC-TOF-FD. The highlight of the year was the run with 4.5 GeV protons. For the first time, an RPC detector with a heating system (based on circulating water) allowing to increase the counting rate capability (decreasing glass resistivity) has been put into operation. However, the current global political and economical situation severely affected FAIR's phase-0 program and casts uncertainty over its schedule. Presently, HADES has no beam time allocated in 2023 and the next run (heavy ions) is scheduled to early 2024. In September 2022, the HADES collaboration meeting was held in Coimbra.

The NUC-RIA group at LIP develops fundamental studies on nuclear reactions and formation of elements in the universe, as well as nuclear instrumentation. In a joint campaign with the LIP RPC R&D group, the team installed, commissioned and operated in the R3B experimental setup a RPC detector to measure with high precision the momentum of relativistic protons emitted in reactions of exotic nuclei on a liquid hydrogen target. At CERN's ISOLDE facility, the team led the IS698 experiment, measuring for the first time a complete angular distribution for the elastic scattering process of alpha particles on unstable isotopes. Through a close collaboration with the GSI-TNA group, NUC-RIA progressed in modeling of kilonovae with calculations of atomic data and in-depth study of the opacity of heavy r-process elements, with results released and published in 2022. Finally, the thermal evaporator managed by the NUC-RIA group for the manufacturing of thin film targets for nuclear reaction experiments has been included as participant facility in the European Nuclear Physics laboratories consortium EUROLABS, an Infrastructure Program of the EU.



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.

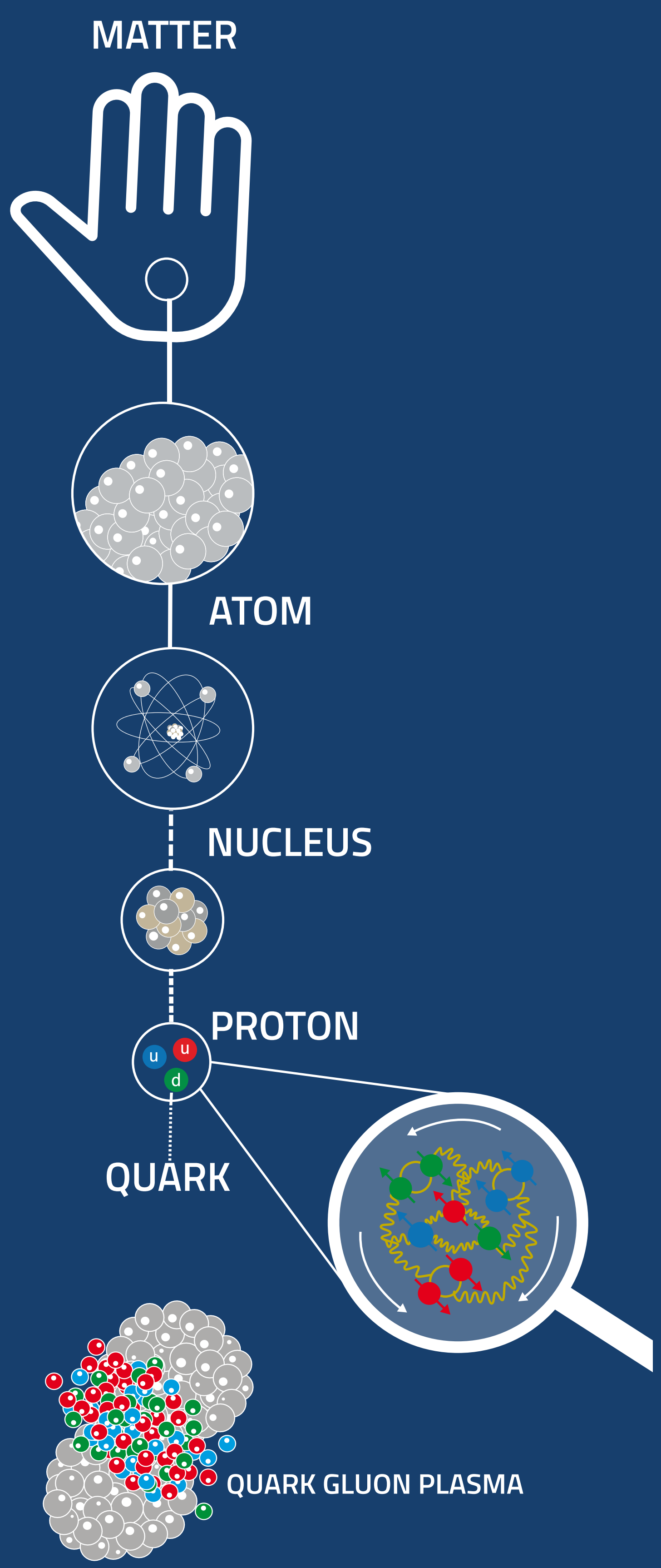
Jumping into theory

NPstrong, the Nuclear Physics and strong Interaction group, joined LIP in 2020. The group works on a variety of topics in nuclear and hadron physics, addressing non-perturbative phenomena in QCD with computational methods. This includes the internal structure of hadrons and their interactions with photons, their production mechanisms, and properties of exotic hadrons, which are not yet understood from first principles and challenge our understanding of the strong force. The fundamental and still open questions behind are the origin of confinement of quarks in hadrons and 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.

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. To describe bound systems of quarks and gluons, we use non-perturbative functional methods (complementary to lattice QCD simulations) that provide ab-initio solutions for QCD's correlation functions. These subsequently enter in the calculation of hadron properties and allow us to make predictions for hadronic observables.

The 2022 highlights build up on ongoing research work and explore new directions. The group improved and extended the calculation of the heavy-light pentaquarks spectrum and computed the spectrum of heavy baryons using functional methods. The goal of these works is to shed light on LHCb discovered states. We further developed out novel method to compute hadron properties on the light front by employing contour deformations in the complex plane for calculations of parton distributions with functional methods. There was also progress in ab-initio solutions of the Yang-Mills sector of QCD (i.e., with gluons but without quarks) providing evidence that mass generation in the transverse sector is triggered by longitudinal massless poles.

The group has been part of several international collaborations and networking activities. Two of its researchers were elected associate members of the HFHF think tank for FAIR physics. A student in the group received the McCartor Fellowship Award.



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EXPERIMENTAL PARTICLE AND ASTROPARTICLE PHYSICS

Cosmic Rays

Messengers from outer space

Planet Earth is constantly being struck by charged particles (electrons, protons atomic nuclei) and energetic photons (gamma rays) expelled by distant stars and galaxies. These messengers from outer space bring information about the history and composition of the Universe. The very wide energy range 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). 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 huge set of data has been gathered at a continuous rate of over 45 million events per day. AMS catches cosmic ray particles directly, before they interact in Earth's atmosphere. The detector is rather sophisticated, with different 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 a medium at a velocity larger than the velocity of light in that medium. Identification is achieved by measuring the Cherenkov radiation emission angle, which is related to the particle's velocity. If the particle momentum is measured by another sub-detector, the particle mass can be derived. LIP holds responsibilities in the RICH operations and monitoring, and in the algorithms used to reconstruct particle properties 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 through the magnetic reversal of the 25th cycle, which is expected to occur during 2023, thus 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. A wavelet analysis tool has been developed to study these time-series and their complex frequency spectra as a function of time and rigidity. This analysis is performed 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. The highest energy cosmic rays are thus 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 water Cherenkov detectors (WCD) 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 showers. Running since 2004, the Observatory has confirmed that highest energy cosmic rays are of extra-galactic origin and most likely accelerated in yet unknown astrophysical source. Still, several open questions remain.

Auger is currently undergoing a massive upgrade to become Auger Prime. For that, scintillation detectors are installed on top of the working WCD, which are equipped with faster electronics. This should enable a better measurement (and disentangling) of the electromagnetic and muonic components of shower at ground. The upgrade will be complete in early 2024 and will most likely run until 2030.

In recent years, the LIP team has been involved in R&D projects on the use of RPC detectors to directly measure the muon component of showers, and for calibration studies of WCD, in collaboration with the Auger groups in Brazil. MARTA consists of a layer of RPCs placed underneath the WCD. In 2022 it was possible to solve in situ the installation difficulties previously encountered. The MARTA WCD-RPC station is now fully equipped and ready to start taking data. The calibration hodoscope (one RPC above and another below the WCD) has been upgraded to the Auger Prime configuration.

In parallel the LIP group has been exploring the Auger data, mainly pursuing the measurement of the muon shower properties in collaboration with the Auger group in Santiago de Compostela (Spain). After the success with the publication on the relative fluctuations in the number of muons, the group focused on structural tasks such as studying the universality of muon distributions. Synergies with the SWGO group currently concern the development of gamma/hadron discriminators to improve the Observatory's sensitivity in multimessenger analyses. The group has been developing 3D outreach tools for shower visualization, virtual visits to the observatory and Auger open data analysis.

Auger open data

The Auger Collaboration has publicly released about 10% of the collected data, together with analyses tools. Several activities were organized in this context.

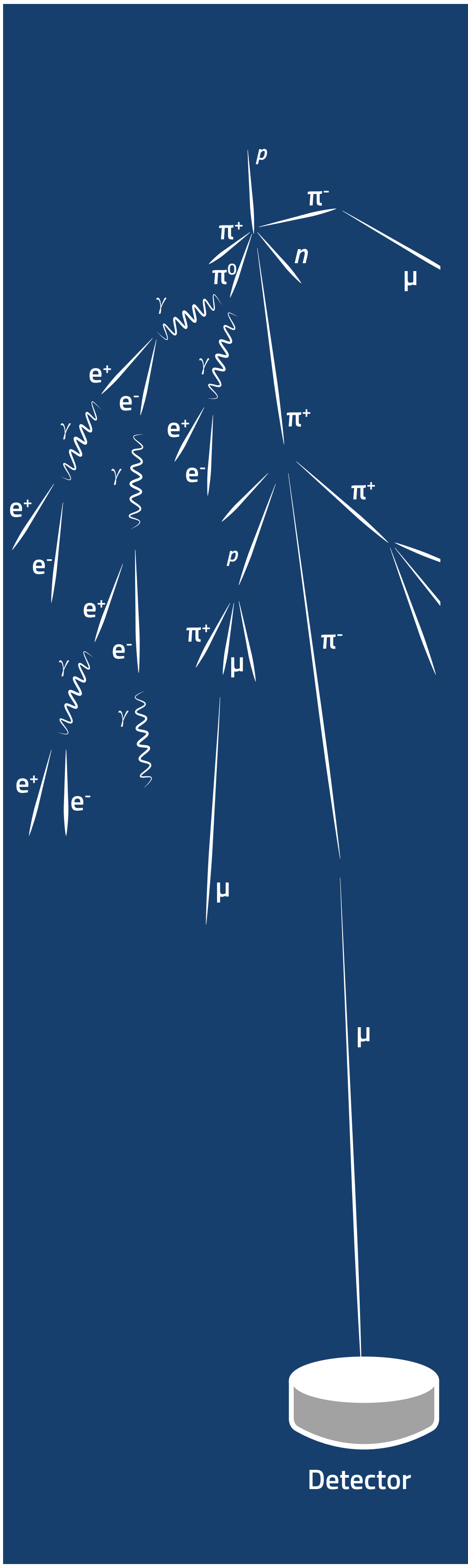
At the top of mountains

The Southern Wide-field Gamma-ray Observatory (SWGO) collaboration was formed in 2019 after a workshop in Lisbon where different groups developing similar projects decided to joint efforts. Today, SWGO comprises 80 research institutions from 14 countries, plus 10 scientists from other countries individually collaborating in SWGO. 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 collaboration aims at producing a complete proposal by the end of 2024, including the physics goal, location, observatory layout, detector design, and cost.

The Portuguese participation in SWGO is focused on specific goals spanning different areas: definition of the science requirements, detector design, development of new analysis methods, education and outreach activities. For 2022, two priorities were defined. The first one was the completion of the detailed design and performance studies of the "Mercedes station," a single-layered small Water Cherenkov detector (WCD) proposed by the LIP group as candidate to be the SWGO detector unit. The second priority was the development of algorithms for gamma/hadron discrimination, i.e., to distinguish gamma-initiated showers from the largely dominant background of charged cosmic rays (initiated by protons and nuclei) showers.

A test set-up for full-size detector station prototypes was installed at the CBPF premises in Rio de Janeiro and is now fully operational. A detailed station thermal simulation model using a professional code (ANSYS Fluent) was finalized and optimized. A team (including a LIP member) visited proposed sites in Argentina, Chile and Peru for two weeks. The Mercedes station is fully implemented in the SWGO simulation.

Gamma/hadron discrimination is paramount in SWGO, as in any gamma ray observatory. The LIP team developed gamma/hadron discriminant algorithms for two energy ranges: at lower energies (100 GeV - 10 TeV), it is a machine learning algorithm based on muon identification in each Mercedes station (using the PMT signal time structure) ; at higher energies (10 TeV – few PeV), it is a discriminant variable that quantifies the azimuthal fluctuations of the particle distributions at ground (LCm). Within the limited statistics available, LCm has demonstrated a discriminant power similar to the number of muons at ground. Both reconstruction algorithms are now part of the SWGO reconstruction framework. A tool to visualize simulation events has been developed, primarily for outreach and education purposes.



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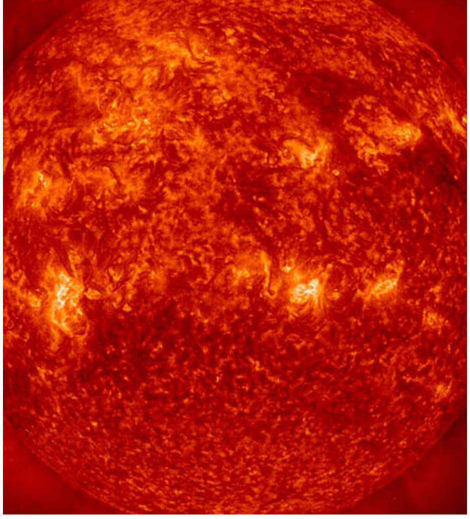


Dark matter and neutrinos

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), LZ dark matter detector at the SURF Laboratory (USA), and the more recently embraced participations in DUNE, one of the leading neutrino physics experiment for the next decades, SHiP, proposed for CERN's SPS (Super Proton Synchrotron), and in the preparation for third generation dark matter search experiments. Furthermore, LIP is actively participating in the most recent LHC experiment, SND@LHC, studying neutrinos at the LHC, from the start of Run 3 in Summer 2022.

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.

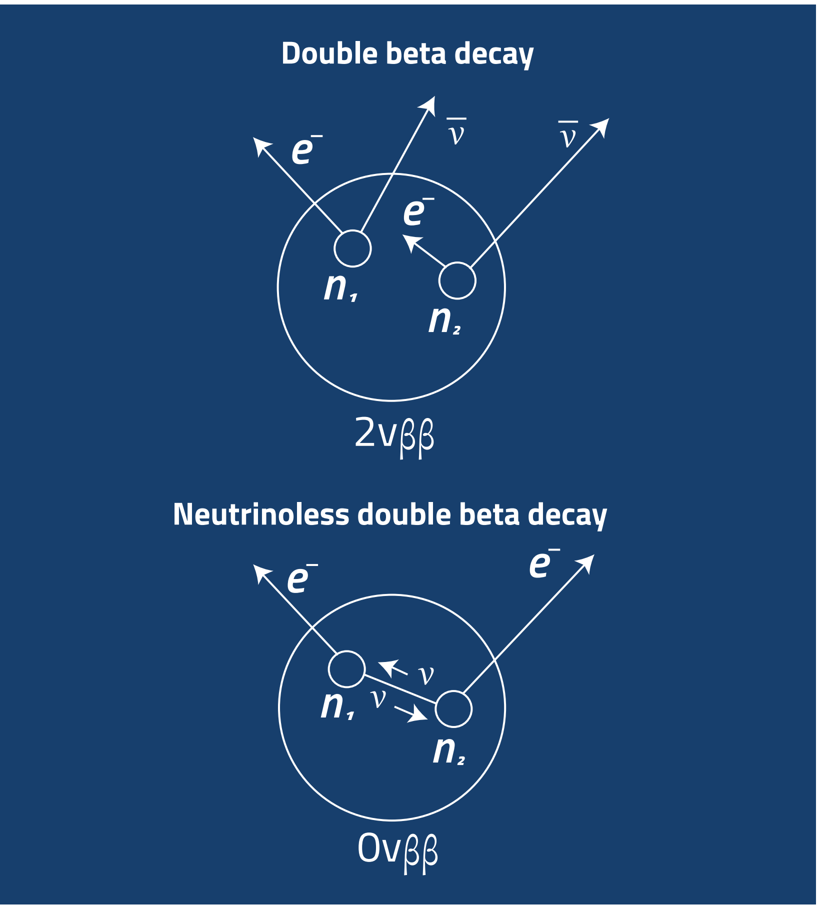
The LIP Dark Matter group is a founding member of the LUX-ZEPLIN (LZ) experiment at the Sanford Underground Research Facility (SURF). LZ utilizes 7 tonnes of liquid xenon as active medium in a dual phase TPC to search for potential dark matter signals. The interaction of a dark matter particle with a 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 occurs. To improve the rejection of background (cosmic rays and natural radioactivity) the detector is placed 1480 m underground inside a double vessel of radio-pure titanium, and there are auxiliary veto detectors. Due to the extremely low background, LZ can be used for other studies such as the search for Xe rare and forbidden decay.

LZ had its first science run in early 2022, with an exposure of 60 live days. The analysis showed the data to be consistent with a background-only hypothesis and cross-section limits have been derived for WIMP masses above 9 GeV/c2: These made LZ the world's most sensitive WIMP search experiment. After a calibration campaign, the collaboration prepared the second science run, which started in December 2022. The LIP group is contributing to many areas of the LZ experiment. It has a leading role in the studies of the LZ sensitivity to Xe neutrinoless double beta decay, is responsible for the detector control system and the online underground performance monitor, and also for the development of data analysis tools for pulse identification and characterization, position and energy reconstruction, and for the backgrounds (modeling, simulation and accounting).

The R&D project on the study of optical properties of reflecting surfaces completed all measurements in 2022. On the other hand, the LIP team is now part of XLZD. Started in 2022, XLZD is a joint venture of most groups in the LZ, DARWIN and XENON collaborations towards a third-generation direct detection WIMP search experiment employing a double phase xenos TPC with about 100 tonnes of xenon. Working groups were formed towards achieving a final design of the detector and planning the experiment.

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. The discovery of neutrino oscillations gave the 2015 Nobel Prize to Takaaki Kajita, from the SuperKamiokande experiment, and Arthur B. McDonald, from the SNO experiment. Another open question about neutrinos is whether they are Majorana particles, i.e., if they are their own antiparticle.



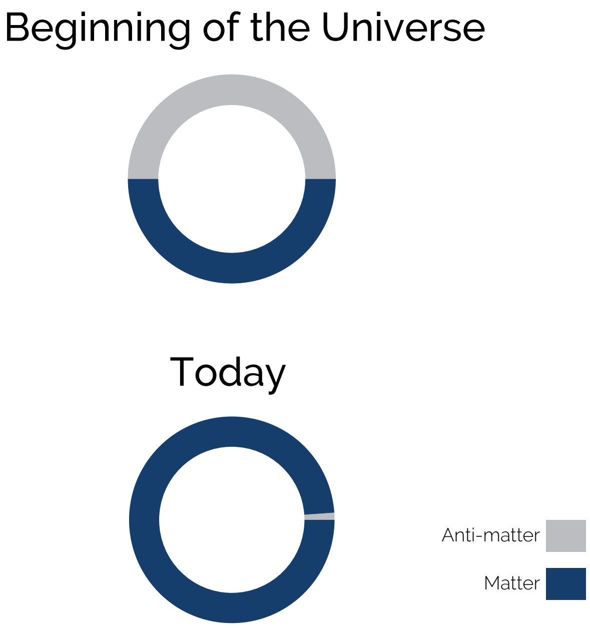
SNO+

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 the SNO+ program: antineutrinos from nuclear reactors and the Earth's natural radioactivity, solar and Supernova neutrinos, and searches for new physics.

The LIP group has been very much involved in the construction of the SNO+ calibration systems and is currently very active in the data analysis of the water and scintillator fill phases (half-full and full detector) phases, with leadership or strong contributions to physics analyses (backgrounds and antineutrino studies) and calibrations, with several results published or in preparation. We highlight the published improved limits for the nucleon decay into invisible channels using the low background water data set, and the submitted paper with the antineutrino analysis in water data (now accepted by PRL and selected as Editor's Suggestion). Following the completion of the scintillator fill in April 2021, the SNO+ detector underwent a top-up campaign for the addition of the fluor to increase the light response. This operation ended in April 2022. The group had a large contribution in the data analysis of top-up campaign data and the following full scintillator data. While the Tellurium purification and loading systems are being commissioned, the detector is now taking high quality data that allows for the measurement of antineutrinos from nuclear reactors and the Earth's natural radioactivity, solar and supernova neutrinos, and searches for new physics.

DUNE

DUNE is a long baseline experiment: neutrino and antineutrino beams will be produced at Fermilab and detected 1300 km away at SURF, in large Liquid Argon (LAr) TPCs (the far detector). 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 group joined the DUNE collaboration in 2018.



Leveraging on the needs of the experiment and the experience of the team, the LIP group is focusing its activities on the design and construction of the far detector calibration systems, both mechanics and electronics. In 2022,the group completed the production and test of the mechanical parts under its responsibility at LIP's Mechanical Workshop and Detectors Lab; participated in the full assembly and operational tests carried out at LANL, and then in the assembly, alignment and installation of the two periscopes at ProtoDUNE at CERN. The group also progressed on the design of the interface electronics between the laser system and the DUNE DAQ and SC and initiated the implementation of the calibration control software. Testing the designs of the calibration systems at ProtoDUNE-II at CERN, as well as analyzing its data, is a priority for the next few years. The LIP team also leads the Calibration and Cryogenic Instrumentation Consortium (one of eleven consortia). The group plans to also contribute to the Near Detector and the neutrino oscillation physics activities.

SHIP and SND@LHC

SHiP at CERN constitutes a long-term, general-purpose facility planned for a new beam dump at the SPS. Its physics program encompasses a high sensitivity search for FIPs (feably interacting particles, arising in various models as mediators between the SM and hypothetical "dark sectors") and a SM precision component involving heavy flavor and neutrino physics. The LIP group is involved in detector development, with focus on RPCs, and physics studies, with focus on machine learning.

With the SHiP timeline delays, activities were refocused in the shorter-term to the SND@LHC project. SND@LHC is the most recent CERN experiment. It stems from the SHiP neutrino detector and is located in the LHC tunnel away from collision points and near the beam-line direction. It shall utilize the potential of the LHC as a neutrino factory to perform measurements with all three neutrino flavors, providing first observations of collider neutrinos. It should facilitate unique heavy flavor measurements. LIP is a founding member of the new CERN collaboration.

The LIP group has been centrally involved in the construction and beam testing of the SND@LHC detector. In 2022 the installation of the whole detector in the TI18 tunnel was accomplished in time for the LHC collisions in Spring. Efficient operation and accumulation of first physics data has followed. The activities of the LIP group spanned commissioning, data taking, validation, analysis, and upgrade studies, in a close collaboration between the Lisbon and Coimbra nodes of LIP. The team has also set up the SND@LHC control room at CERN, integrated in the CMS remote control centre, used since the start of physics data taking.
The analysis of the collected data set has been initiated. A preliminary selection was devised, resulting in a golden sample that yielded the first neutrino candidates detected by SND@LHC. The LIP group presented a proposal to install a telescope, based on sealed RPC technology, to monitor the muon flux in different angular regions. This upgrade has been approved by the collaboration, and aims at being installed for operation during the ongoing Run 3.

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Development of new instruments &methods

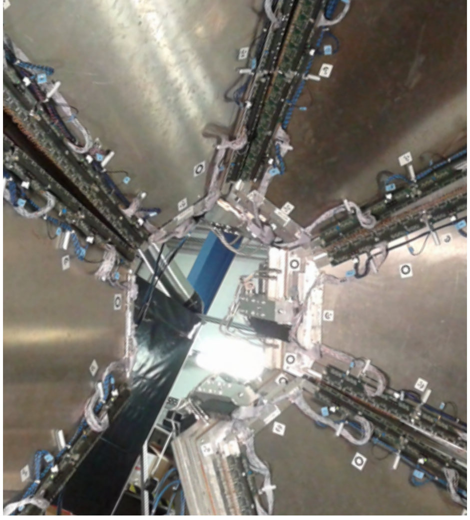
▪ Detectors for particle and nuclear physics ▪ Health and biomedical applications ▪ Space applications

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 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. The laboratory holds 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 ICNAS, the institute for nuclear health applications at the University of Coimbra, CTN/IST, the centre for nuclear technology at the University of Lisbon, and several hospitals, medical research centres, 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, and a partner of the Portuguese Space Agency.



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 specialties include Resistive Plate Chambers (RPC), neutron detectors, gaseous and Xenon-based detectors, optical fibre 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 addressing societal challenges, from nuclear and particle physics to medical physics, from rugged outdoor muon detection systems to helium-free neutron detectors, confirming LIP as a world leader in the development, design, and construction of RPCs. The group presently works in a number of research directions.

RPC-PET: medical imaging

The development of RPC-based devices for medical imaging through Positron Emission Tomography (PET) is a priority for LIP. The group is currently focused on HiRezBrainPET, the human-brain PET device developed in collaboration with the company ICNAS Produção. The project for the production of a full prototype was completed in 2022. Tests demonstrated a sub-millimeter spatial precision and the ability to create images of small brain structures in phantoms. For further details, please go to the Health and Biomedical Applications research line.

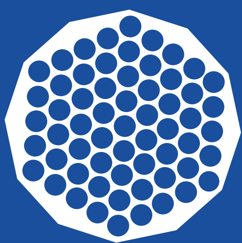
Time and position sensitive RPC

Many large particle physics experiment presently use RPC-based detectors: their very good time precision is ideal for

Detectors at LIP

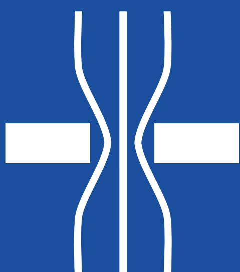
Resistive Plate Chambers (RPC)

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.

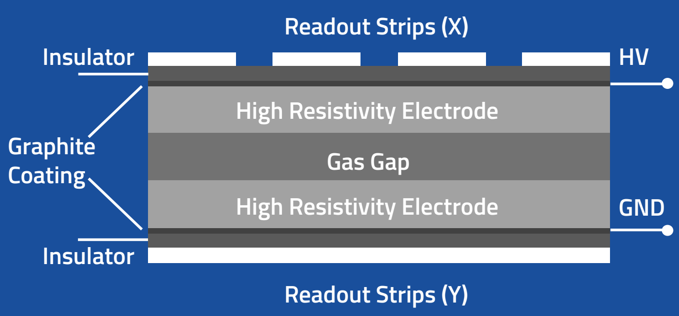


Patterned Gas Detectors (PDG)

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

trigger or timing, and it continues to be one of the main technologies for particle identification (using the time of flight technique, TOF), specially when implementation in large areas is needed. The LIP RPC group develops and builds RPC detectors for particle and nuclear physics experiments using an innovative technology that allows for 98% efficiency and 50 ps time precision. In 2021 and early 2022 two such systems were installed in the two experiments in which LIP participates at GSI, for the FAIR phase-0 runs. In 2022, the new forward TOF detector for HADES (RPC-TOF-FD) run for six weeks. The new TOF detector for the R3B collaboration was successfully operated at two beam times. For further details, please go to the Structure of Matter research line.

As for position information, it depends essentially on the configuration choice for the readout strips and data acquisition channels. The precise measurement of position in combination with time is also of interest for TOF-based particle identification. In addition, it finds direct application in muon tomography. Cargo container muon scanners STRATOS were developed, prototyped and built at LIP for company HIDRONAV (Spain). Each STRATOS unit is a 2 m x 2 m telescope (four RPC planes inside) with a homogeneous efficiency around 98%, 2D spatial precision better than 1 cm and industrial design. Preliminary tests in scattering tomography mode showed the capability to identify high Z materials (e.g., tungsten and lead) after a few minutes of data acquisition. In the framework of an exploratory project on muon tomography of geological structures, the muon telescope fully integrated in 2021 started field operation by muographing the physics department building in Coimbra, and continued inside the Waldemar gallery at the former Lousal mine (today a science centre). Remote detector operation worked successfully and detector performance is stable. Muography data analysis is ongoing. For further details, please see the Muon Tomography report, in the Science and Society section.



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.

Autonomous RPC

The development of autonomous and reliable RPCs, with very low gas consumption, able to operate under harsh conditions and with little maintenance is of great interest for several applications. In particular, sealed RPCs will be a breakthrough in the field, and the LIP team has a strong record in this domains: in 2020, chambers have been successfully tested at pressures from 1000 mB down to 400 mB (about 6000 m altitude) and sealed 0.5 m x 0.5 m RPC have been in operation for eight months with no performance degradation. During 2022, a 1 m x 1 m double gap sealed chamber (the target size and configuration) has been assembled and fully instrumented. It is in the process of full characterization (measurement of time resolution, efficiency and charge spectrum over time) showing a stable performance after a few months of operation. First results were presented in the XVI RPC Workshop.

RPC-based neutron detectors

Neutrons are a unique probe for revealing the structure and functioning of matter from the microscopic to the atomic level. Neutron-based techniques can be applied to a wide range of scientific domains, including physics, chemistry, material science, geology, heritage, and life sciences. These techniques mainly rely on neutron scattering instruments, equipped with advanced detectors available only in large scale facilities. Such facilities, and in particular the future European Spallation Source (ESS), will be prominent global research infrastructures useful to academia and Industry. Until the so-called ^{3}He crisis, the gold standard for neutron detection was based on ^{3}He, a stable and rare isotope of helium, due to its high thermal neutron capture cross section. The ongoing global shortage of ^{3}He motivated the development of alternative neutron detection technologies meeting the requirements of a new generation of instruments: high rate capability, good spatial and time resolution.

The LIP group has introduced a pioneering concept of an RPC-based detector lined with $^{10}B_4C$ as neutron converter, aiming at high resolution and high count rate position sensitive detectors for cold and thermal neutrons. The first development stages were conducted in partnership with ESS and FRMII in the framework of the EU project SINE2020. This technology offers very good spatial and time resolution, modularity, robustness, scalability, and low cost. We demonstrated that it could provide detection efficiencies above 60% and is well suited for neutron imaging (spatial resolution 0.25 mm). During 2022 we designed and completed the construction of a nRPC-4D proof-of-concept demonstrator in the framework of the project "Fast timing high resolution nRPC-4D detector concept for neutron science", funded by FCT. The goal is to demonstrate that this type of detector can provide 4-dimensional readout capability (XYZ coordinates and time). Preliminary tests performed with the demonstrator on a neutron beam line at Paul Scherrer Institute (PSI), showed its capability to readout the neutron time of flight (ToF) as well as the XY and Z coordinates of detected neutrons.

As a spin-off project, the group is developing a fast neutron detector concept based on the ^{10}B-RPC technology. A potential application is the measurement of beta-delayed neutron emission probabilities of exotic neutron-rich nuclei (e.g., in ISOLDE at CERN).

Gaseous detectors and RD51 collaboration

The general purpose of the group is to carry on R&D on liquid xenon physics and instrumental/technological issues relevant for the development of particle detectors based on liquid xenon (and potentially other liquefied noble gases). The main focus is currently on application of MPGDs (Micropattern Gaseous Detectors) in double phase xenon (liquid/gas) and the development of novel methods for the readout of those detectors according to the scientific programme of the RD51 Collaboration at CERN. In 2022 the main task was to study a novel method of electron extraction from liquid xenon (and potentially liquid argon) proposed by our group. This method is based on using a multihole two-electrode structure freely floating on the surface of liquid xenon - a Floating Hole Multiplier (FHM). With this idea in mind, two setups have been completed, one at LIP in Coimbra and the other at Weizmann Institute of Science (Israel), which is our close partner within RD51. These setups allowed us to prove the principle by observing electron extraction from liquid xenon with a floating THick Gaseous Multiplier (THGEM) and to study the behaviour of liquid xenon in contact with a THGEM-like structure at sub-millimetric level. The novel concept has been proven: the electrons drifting in the liquid were observed to be collected into the THGEM holes, extracted to the gas (in the hole), and to induce secondary scintillation in the gas thus providing the typical S1/S2 event signature.

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 electrons and ions (both positive and negative) 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.

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DEVELOPMENT OF NEW INSTRUMENTS AND METHODS

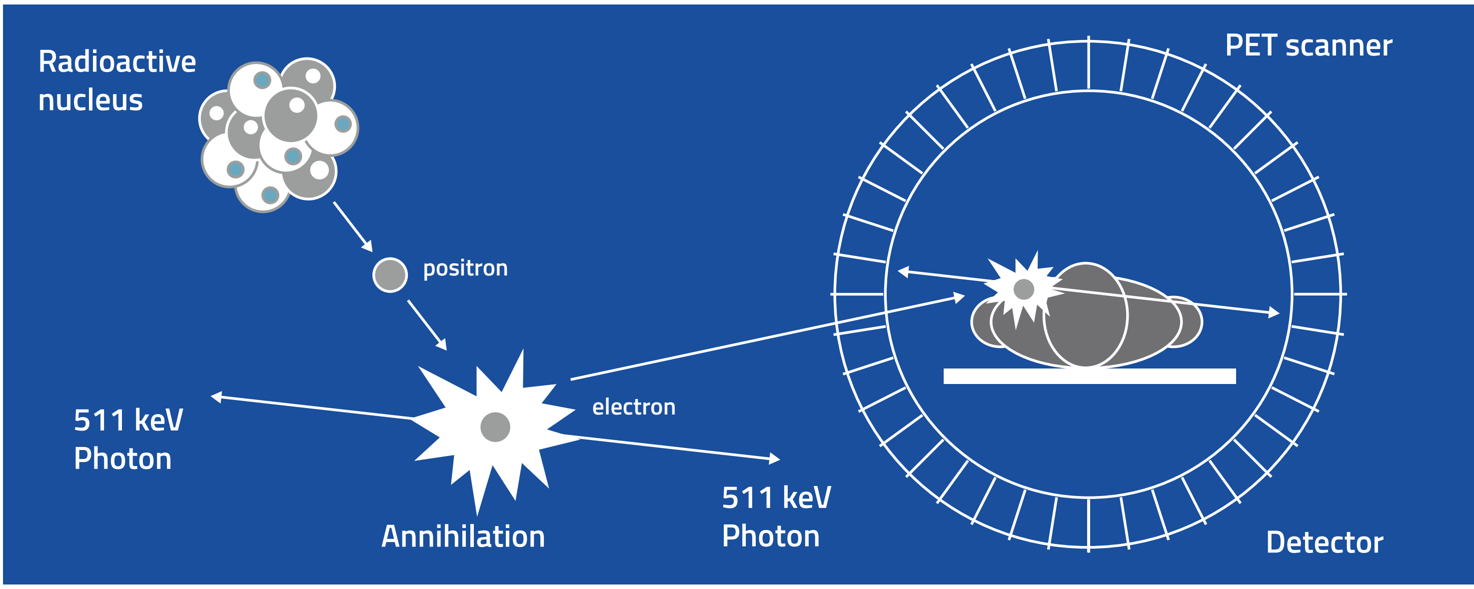
Health and biomedical applications

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 centres.

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 neighboring 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 team at LIP for a number of years. A high-resolution, small animal RPC-PET scanner developed at LIP is installed at ICNAS since 2014. Hundreds of tests have been performed in mice, with goals such as studying degenerative diseases or testing new drugs. This technology has now been applied for human brain PET, in the framework of the project HiRezBrainPET. This equipment has the potential to change the paradigm in the diagnosis and investigation of diseases of the central nervous system, for example by allowing 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 better treatment planning. The evaluation of the BrainPET scanner started in early 2022. The most important results are a spatial resolution better than 1 mm FWHM. This resolution is strongly limited by the non-collinearity of photons in PET events, as the resolution of the detector for cosmic rays is below 100 um. In a phantom of a human brain with an average activity concentration of 6 kBq/ml and 50 kBq/ml in the striatum, it was possible to resolve the striatum chambers, demonstrating the capability of imaging a realistic brain phantom. The scanner shows a sensitivity of 0.09%, equipped with less than half of the detectors it can accommodate. Next steps are the full evaluation according to international standards, tests and imaging of human subjects.



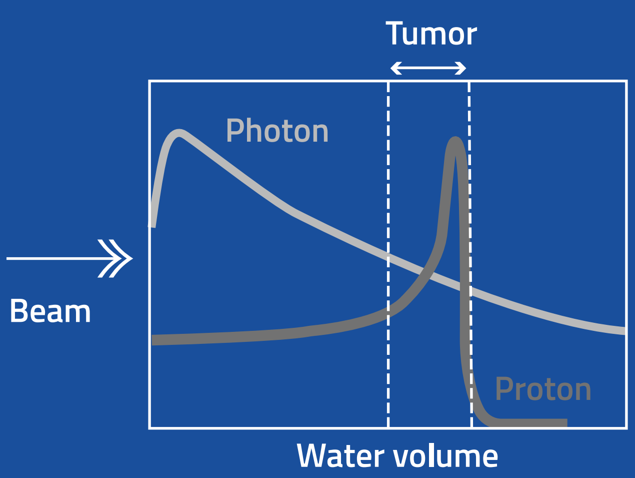
Advanced Radiotherapy and Charged Particle Therapy Applications

The Prototera Association was established in 2019 to promote and develop a national research and training network in advanced therapies and associated technologies in Portugal. The association is committed to enhancing research infrastructures, training, and healthcare associated with the treatment of cancer patients in specific areas that encompass the effects of high-energy radiation on biological and material systems, high-energy particle beam therapies and advanced medical imaging, among others.

LIP played a pivotal role in creating the Prototera association, along with CTN/IST, ICNAS/UC, and the Portuguese network of Oncology Institutes. Internally, there was an effort to bring together LIP groups and researchers developing applications that could lead to technology transfer from particle physics and associated particle detection technologies to radiation and particle therapy. The high interest of students in these fields was supported by the Prototera FCT doctoral Programme, coordinated by LIP.

Proton-therapy

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



In the past years LIP has thus been following a strategy aimed at providing advanced training in the field of radiation and particle therapy applications of physics to increase expertise in Portugal in support of a future charged particle therapy facility. However, the future of such a facility for cancer therapy in Portugal is presently undefined. For this reason, LIP is redefining its strategy in a two-fold way:

• Pushing forward an International Network for Advanced Radiotherapy, in which LIP will promote with its partners the advanced training of physicists, medical physicists, and clinicians at Iberian and European level, exploring the opportunities that arise from the foreseen installation of 13 proton therapy facilities in Spain in the next years (besides the two facilities already existing in Madrid) and the collaborations that have been put in place throughout Europe, in particular with Prototera.

• Creating at LIP a Radiation Engineering Centre for advanced training in the applications of ionizing radiations to different fields (health, materials, and space). This will bring together the expertise existing in the laboratory in the different application fields, thus consolidating LIP's research in charged particle therapy applications and enhancing the laboratory's contribution to advancements in the field

Real-time beam monitoring and imagiology

Since several years researchers at LIP are committed to the development of instrumentation for radiotherapy. The aim is to optimize treatments in near-real time, so that the irradiation can better accommodate the tumor and spare surrounding healthy tissue. In orthogonal ray (OR) Imaging techniques, this is done using x- or gamma-rays emitted orthogonally to the treatment beam. The rotation-free, low-dose imaging capabilities of such techniques are two of their strengths. We the last few years, the team developed both experimental work and ever more realistic simulations, focusing mainly in orthogonal prompt-gamma imaging (O-PGI) for proton therapy monitoring in a variety of situations (head-and-neck, pelvis, lung, total-body irradiation in pediatric tumors, among others) in a collaboration between LIP and the University of Coimbra.

During 2022, the team developed the simulation of a full system for assisting head irradiation. A multi-slat prompt-gamma camera has also been simulated and optimized. A small-scale prototype is currently being built at LIP (four slats of tungsten interleaved with three rows of YAP scintillators) and will be tested in a clinical proton cyclotron at HollandPTC (Delft, the Netherlands).

In-beam time-of-flight PET for monitoring proton therapy (TPPT) is a consortium between PETsys Electronics (leading company), LIP, the universities of Coimbra and Lisboa, the University of Texas at Austin, and the MD Anderson Cancer Center, in Houston (USA). Our involvement concerns simulation, and the goal is to adapt DICOM-based (Digital Imaging and Communications in Medicine) computed tomograms (CT) and proton therapy treatment plans into the GEANT4 simulation framework, so that both O-PGI and PET simulations can be conducted based on this information. Several tasks towards this goal have been completed in 2022, including optimizing the procedure for building a voxelized anthropomorphic phantom from the CT of a patient and developing a probability-based approach for generating positron emitting nuclear species for treatment.

Radiation dosimetry and applications for advanced radiotherapy

Knowledge of the biological efficiency of ionizing radiation in organs and tissues is essential to obtain more precise parameters for radiotherapy planning. This efficiency depends on physical properties, such as linear energy transfer and dose, chemical effects, and biological factors. This can be studied through in vitro and in vivo irradiation experiments of various cell types. Knowledge of spatial distributions and dose at the sub-cellular scale is particularly important in the case of charged particle therapy. LIP has a long experience in the development of instrumentation, simulations, and calculations of fundamental physical parameters relevant in dosimetry. Currently, the main goal of the LIP dosimetry applications group (RADART) is to contribute to the analysis and interpretation of research studies in forefront radiotherapy modalities. Activities are divided in two main areas: New detectors and materials for high-resolution dosimetry (i.e., capable of measuring energy depositions at micro and nanometer scales); New modalities and applications in radiotherapy (RT) (using simulation tools extensively to study the physical and physicochemical effects of radiation and from these infer biological effects).

In 2022, ongoing projects included: development of a detector for radiobiology and quality assurance applications in charged particle RT, able to measure energy depositions at the sub-millimeter scale using scintillating plastic optical fibres; Development of materials for micro- and nanodosimetry; Development and application of computational models based on MC simulations (TOPAS-nBio) to understand the biological effects of radiation on cells internalized with high-Z nanoparticles; Modeling and comparing chemical effects in conventional and FLASH-RT via simulations and development of a novel strategy for multibeam FLASH-PT; Study the effects of proton therapy (PT) and the potential impact on the control of neurodegenerative diseases. The group's projects are developed in collaboration with other national (C2TN, IBEB, BioISI, ICNAS) and international research centers (ICPO, DKFZ, CMAM). Particularly relevant is the connection with the groups led by J. Seco (DKFZ) and Y. Prezado (ICPO). The projects have a large contribution from the LIP infrastructures: LOMaC, MW&DL, e-CRLab, and Computing Infrastructures.

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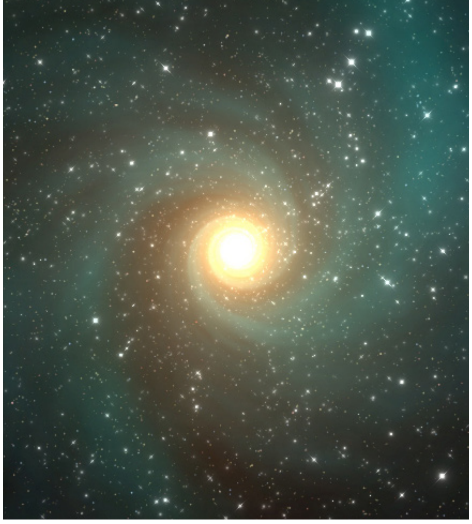


Space applications

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, and of the Portuguese Space Agency (PT Space).

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. The LIP SpaceRad group addresses questions posed by ionizing radiation in space. Its competences include all the areas on ESA's roadmap for this domain: radiation environment analysis and modeling; radiation effects analysis tools; radiation measurement technologies; radiation hardness assurance of EEE (Electrical, Electronic and Electromechanical components).

Currently SpaceRad leads a project for the support of the quality and calibration of the data of two radiation monitors flown in two ESA Planetary Missions: the BERM instrument on board of the BepiColombo mission to Mercury and RADEM on board of the JUICE mission to the Jovian System to be launched in April 2023. These monitors will provide unique data sets and consequently will be used as windows to the Heliosphere for multi-observation of Solar Particle Events and for energetic particle propagation studies. The BERM calibration and in-flight data analysis was addressed, including a cross calibration with the SIXS instrument also onboard of BepiColombo.

SpaceRad is also preparing for future Mars and Lunar missions, for which it can contribute with the predictions of dMEREM, the detailed Martian Energetic Radiation Environment Model, which will be adapted to the description of the Lunar and Cislunar radiation environments. dMEREM was developed at LIP in 2009, within ESA's contract Martian Radiation Environment Models, and 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 on the Martian surface was performed and published.

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) and is responsible for the analysis of the in-flight data of AEEF's particle spectrometer and radiation monitor MFS, and also of its CTTB (Component Technology Test Bed). A paper on the pioneer study of the effects of radiation in GaN electronics aboard the CTTB was published in Nature Scientific Reports. This study was done in collaboration with Instituto de Telecomunicações at Universidade de Aveiro, responsible for the GaN experiment aboard the CTTB.

Astrophysics instrumentation in space

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) polarimetry has known very few developments, despite its great potential to open a new scientific observational window.

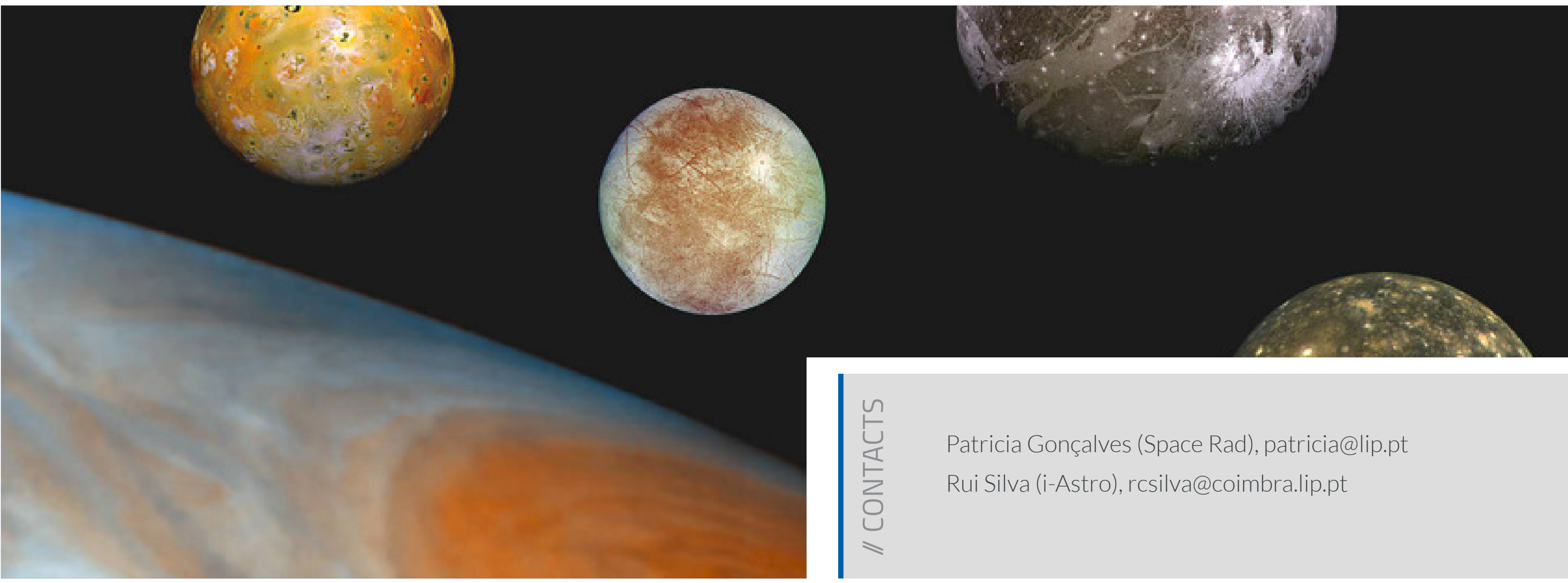
LIP's Astrophysics instrumentation (i-Astro) group holds high-level competences in instrumentation for astrophysics with emphasis in x- and gamma-ray polarimetry. The group contributes to the development of space instrumentation based on semiconductor detector planes (CdTe, CzT, Si, Ge), scintillators (CsI) or gas-filled detectors with polarimetric capabilities. More recently, the competences of the group have been applied to the study of the effects of Terrestrial Gamma-ray Flashes (TGFs), which are bursts of gamma rays produced in Earth's atmosphere, which may affect the health of aircraft crews and passengers.

The group develops its research activities in the framework of mission proposals to ESA, NASA and EU, in the domains of x- and gamma-ray space astrophysics and terrestrial gamma-ray flashes. i-Astro is currently part of the EU project consortium "Activities in the High Energy Astrophysics Domain" (AHEAD2020) as well as of the NASA mission proposal consortium "All-sky Medium Energy Gamma-ray Observatory" (AMEGO). These are long term projects whose technology and science case are validated and improved in previous small-size space- and balloon-borne missions. i-Astro is currently leading two small-size ESA funded projects: Gamma-ray Laue Optics and Solid State detectors experiment (GLOSS) onboard the ISS; and TGF and High-energy astrophysics Observatory for gamma-Rays (THOR) on board the Space Rider. In these projects our group is developing gamma-ray and particle detection instruments for high-energy astrophysics, including front and back-end electronics.

The AHEAD2020 EU funded project started in March 2020. i-Astro is part of work package 11 — Space Experiments for HE Astrophysics & Multi-messenger Astronomy activities. We are developing a demonstrator for a 4U CubeSat Compton Telescope (COMCUBE), that may offer a game changing GRB polarimetric capability in the few hundred keV range.

The GLOSS project onboard the ISS started in July 2021. It is led by LIP in collaboration with Active Space, University of Beira Interior (UBI), and several Italian research institutions (INAF, University of Ferrara, Istituto dei Materiali per l'Elettronica e il Magnetismo, IMEM, Parma). GLOSS will test and characterize CZT samples onboard the ISS Bartolomeo platform. The goal is to assess the effects of orbit radiation environment on a CZT-based instrument of the type that could be used in a future gamma-ray observatory for a Low-Earth Orbit (LEO) mission.

The TGF and High-energy astrophysics Observatory for gamma-rays on board the Space Rider (THOR-SR) mission is a high-energy astrophysics pathfinder mission designed to explore a range of phenomena that includes gamma-ray astrophysics' emissions (such as the Crab Nebula or GRB emissions), space weather and terrestrial gamma-ray flashes, addressing a major aviation safety concern.



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Computing

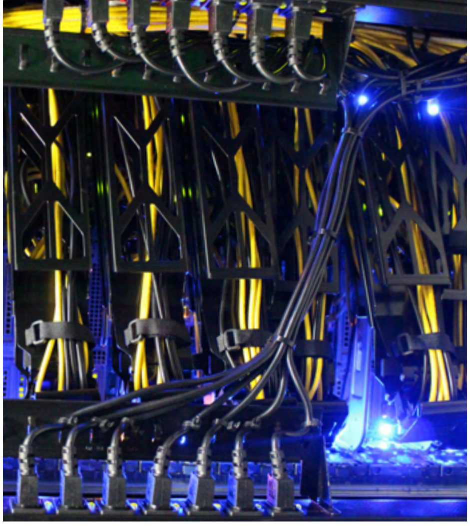
▪ Scientific computing

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

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 arrival of the SPAC group very much strengthened this domain and opened new research lines in social physics and complexity.



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.

Distributed computing and digital infrastructures (GRID)

The Distributed Computing and Digital Infrastructures Group provides the information and communication technology (ICT) services that support research, innovation, education, outreach and administrative activities at LIP. The group has extensive experience in delivering compute and data oriented services for research, including the operation of the Portuguese Tier-2 facility integrated in the CERN Worldwide LHC Computing Grid (WLCG), a global collaboration of more than 170 computing centres in 42 countries, linking up national and international e-infrastructures to serve the LHC experiments. In 2022 the LIP Tier-2 in the WLCG executed more than 471,000 jobs and delivered more than 165,631,000 HEP Spec06 normalized processing hours, yielding a 70% increase. Overall, the reliability was 97%.

The group activities bridge at international level with science related e-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 research communities beyond high-energy physics. In the framework of IBERGRID and EGI, 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 organized the IBERGRID 2022 conference joining Iberian researchers, developers and infrastructure managers in Faro. This also included the first EOSC tripartite event in Portugal and Spain joining the EC, funding agencies and researchers.

The development of the group competences and capabilities is backed by the participation in R&D&I projects on the development and exploitation of digital technologies applied to both compute and data intensive science. Ongoing activities focus on data processing using cloud computing, High Throughput Computing (HTC), High Performance Computing (HPC), and machine learning (ML).

During 2022 the LIP group was part of several European projects, namely in: EGI-ACE, supporting cloud applications and working on solutions for high performance computing integration; EOSC-Future, coordinating the software management activities; DT-Geo, providing solutions for containerization, integration and software quality for a digital twin on geophysical extremes (earthquakes, volcanoes and tsunamis); interTwin, delivering quality and software management for a generic framework to support interdisciplinary digital twins; AI4EOSC working in the development, provisioning and quality assurance of the DEEP AI platform; iMagine, providing support to the use of the DEEP AI platform for aquatic science. The group also participates in the BigHPC project in the framework of the UT-Austin-Portugal program, contributing to the quality assurance and integration of a platform for big data applications.

The EOSC-Synergy project, aiming to align infrastructures and policies in ES, PT, UK, CZ, DE, SK, PL and NL, finished with a very successful review where the work coordinated by LIP was highly praised. The consortium was encouraged to exploit these developments and apply to a follow-up project. LIP worked in the development of a platform for quality assurance and assessment of software, services and data. Four of the above projects started in 2022: DT-Geo, interTwin, AI4EOSC and iMagine.

In the EuroHPC initiative for a world class supercomputing ecosystem in Europe, LIP finalized the EuroCC project that established a national competence center for HPC. LIP coordinated the awareness and communication task and participated in the support, consulting, and training. A follow-up project EuroCC-2 was prepared and will start in 2023.

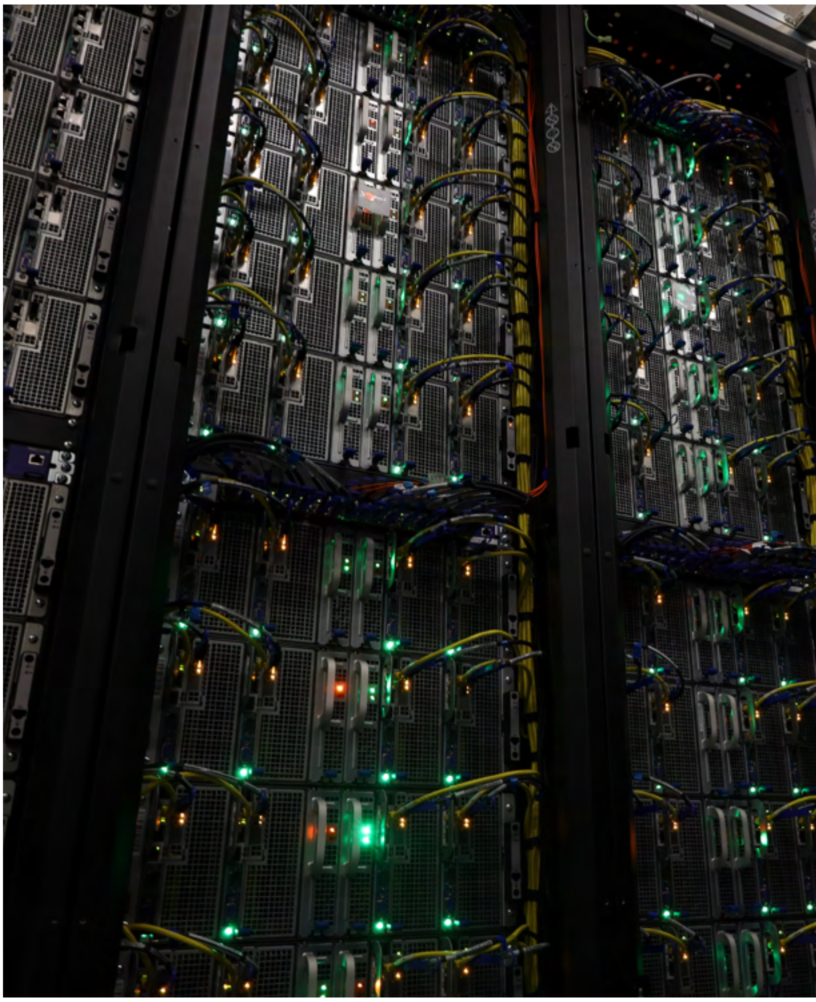
The group leverages its expertise to deliver scientific computing services to the wider Portuguese scientific and academic communities via the Portuguese National Distributed Computing Infrastructure (INCD) LIP participated in the management of INCD and coordinated all technical activities.

LIP coordinated INCD's participation in R&D&I projects including: implementation of a catch-all repository for research data in collaboration with FCT; implementation of Earth observation services exploiting Copernicus data in the C-Scale project; delivery of cloud services to support thematic services in biodiversity and coastal engineering in the EGI-ACE project; integration of compute and data services in the EOSC-Synergy project; and hosting of deep learning services in the iMagine project. Steps towards a collaboration in the European Partnership Agriculture of Data started.

Under LIP's coordination, in 2022, INCD delivered 43,050,000 CPU hours to computing projects in all domains. An international tender to improve the INCD capacity was performed, resulting in 7000 CPU cores, 3 PB of online storage and up to 20 PB of tape storage to serve the Portuguese research community. In Lisbon the existing HPC cluster was complemented and the connectivity was upgraded to 100 Gbps. In Vila Real a new operations centre was created to provide cloud and HPC services. Tape based storage was installed in Coimbra.

Through INCD, LIP is also engaged in national activities related to High Performance Computing (HPC) in the context of the National Advanced Computing Network (RNCA). LIP represented INCD in the national advanced computing network (RNCA) council and related work-groups. Within the RNCA activities, LIP provided support to computing projects selected within the 2nd FCT Call for Advanced Computing Projects (CPCA) and participated in the preparation and evaluation of the 3rd CPCA, whose selected projects will start in 2023. The formal accession of INCD to the RNCA network as an operational centre was signed.

Finally four proposals to Horizon Europe were approved and the projects started in 2022. AI4EOSC and iMAGINE focus on the support to artificial intelligence (AI) applications. DT-GEO and interTwin focus on digital twins in multiple domains, from Earth sciences to particle physics and climate research.



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Social Physics and Complexity (SPAC)

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 behaviors. There is a growing perception that physics will be fundamental to study sociology and even psychology. Leading scientists are calling this new science "Social Physics" and arguing that, in some ways, complexity science will study the physics of human interactions.

SPAC uses large scale computational tools to study societal challenges, especially in disease forecasting, human behavior, and public policy, using a complex systems approach. It is a very multidisciplinary team 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 behavior 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.

SPAC joined LIP during the second half of 2020. Its work is mainly funded by a 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)". In 2022, SPAC furthered the goals of the FARE project, namely by establishing the computational and data infrastructure to support the necessary future analysis, designing the large-scale survey, (almost) completing the core dataset on fake news and Tweets, and assuring the quality and safety of the data pipelines and processes. In September, SPAC was awarded an ERC Proof-of-Concept grant (FARE_Audit) to develop an auditing tool for search engines.

In parallel, the group finished a long-term project, in collaboration with the National Ministry of Health, focused on using different datasets to "now-cast" respiratory diseases and minimize their burden to health systems. SPAC organized a workshop with different stakeholders in the field, including researchers, medical doctors and data scientists, working in different public and private institutions, and released a proposal for a monitoring system for transmissible respiratory diseases, co-authored by all participants and other external experts. This work has led to one MSc thesis, three manuscripts (all currently undergoing peer review) and a white paper.

SPAC is strongly involved in science communication, outreach and citizen engagement. SPAC's work received wide media attention, both national and international, and the European Research Council highlighted SPAC's work in a dedicated piece.

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. in a broad way, the development of the field of "Social Physics" will rely strongly on applying to human interactions theoretical models from physics (ex. diffusion, statistical physics) and simulation techniques (ex. Monte Carlo). Therefore, it is expected that strong collaborations will arise with different LIP research groups. These collaborations can easily expand to international partners, including CERN and others that are strongly growing their DS&AI (data science and artificial intelligence) resources.

SPAC's work received wide media attention, both on disinformation and COVID-19 control.

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 existing high-level expertise. The research infrastructures in Lisbon, initially 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, and continuing the instrumentation lab created at LIP's foundation for the development of front-end electronics and data acquisition systems for the CERN experiments in which LIP was involved.

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

REASEARCH INFRASTRUCTURES

Computing

The LIP Computing Infrastructures provide scientific computing services to LIP and to the wider Portuguese scientific and academic communities in the context of the national multidisciplinary digital infrastructure INCD. LIP operates the Portuguese Tier-2 facility integrated in the CERN Worldwide LHC Computing Grid (WLCG).

LIP participates in the management of INCD and coordinated all technical activities. Under LIP's coordination, in 2022, INCD delivered 43,050,000 CPU hours to computing projects in all domains. An international tender to improve the INCD capacity was performed, resulting in 7000 CPU cores, 3 PB of online storage and up to 20 PB of tape storage to serve the Portuguese research community. Through INCD, LIP is also engaged in national activities related to High Performance Computing (HPC) in the context of the National Advanced Computing Network (RNCA). For details, please go to the LIP Computing and Digital Infrastructures (GRID) group report above. LIP Computing bridges at international level with science related e-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 also collaborates with several research communities beyond high-energy physics. In the framework of IBERGRID and EGI, 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.

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 characterization and test of optical fibres, scintillators, and light sensors; and equipment to measure absolute light yield.

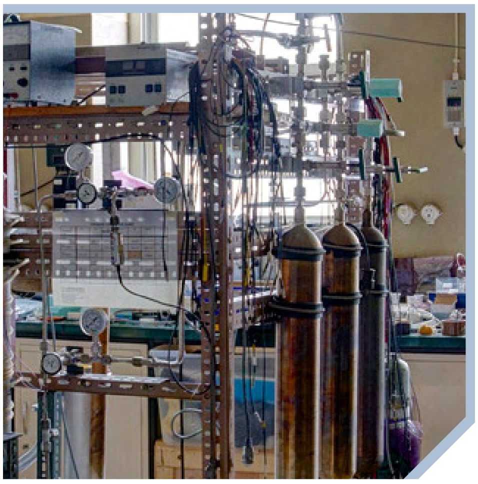
In 2022 LOMaC focused mostly on:

1. Research on new scintillating materials for future detectors based on PEN (Polyethylene Naphthalate) and PET (Polyethylene Terephthalate), in collaboration with the Institute for Polymers and Composites of the University of Minho (IPC/UM), and in the context of the DLight Exploratory Project and LIP's FCC group. Small scintillator plates have been produced by injection moulding and tests showed promising light yield and transparency;
2. Radiation hardness studies of TileCal scintillators and WLS fibres, focusing on HL-LHC and future detectors. The study uses data from TileCal calibration systems collected along the years of LHC runs. The tests of the high voltage distribution boards for the Phase II upgrade of ATLAS are also done at LOMaC;
3. Development of a high-resolution dosimeter prototype (submillimetric resolution), in collaboration with the dosimetry applications group (RADART) and e-CRLab. A first prototype has been mounted.

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 for 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 3 x 2 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 companies. The main projects schedule for 2022 were completed respecting the pre-defined delivery times, even if work that was not foreseen was required in all cases. The work is often developed in close collaboration with the Detectors Laboratory (DL). Highlights were the construction of most mechanical parts for the ProtoDune-II calibration system, mechanical frames for the SND@LHC detector, and contributions to experimental devices and setups to be mounted at LIP in the framework of the RD51 collaboration, RADART group and Neutron Detectors group. The MW also contributed to the construction of two cloud chambers for outreach purposes. Along the year, unexpected new projects (some medium size and many "small" requests) arised and could be accommodated. The MW significantly increased the number of external orders, especially among universities and national research centers. Some of the external clients in 2022 were: CNC-Centro de Neurociências e Biologia Celular, ITAV-Instituto do Ambiente, Tecnologia e Vida, SerQ-Centro de Inovação e Competências da Floresta, IT-Instituto de Telecomunicações, UC-Biotech, Bioelectronics & Bioenergy Research Lab, ICNAS-Produção, Biophysics group, LIBPhysGian, FireLab, among other.

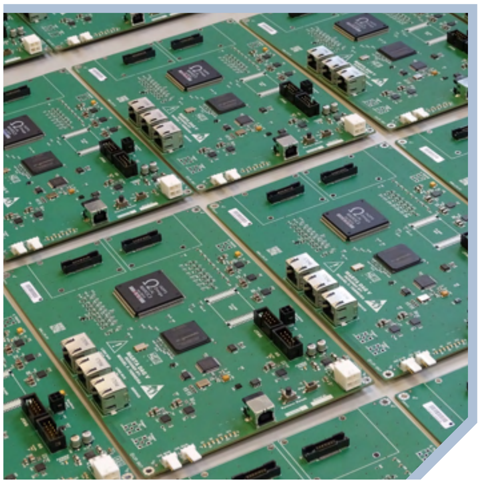


REASEARCH INFRASTRUCTURES

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 laboratory's research groups. Along the years the DL has been continuously updated considering 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 electronics circuits and vacuum systems, and the design, construction and testing of particle detectors. DL's services span from the project design phase to installation and maintenance, following a procedure similar to industry's.

In 2022 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, the support to LIP groups in their R&D activities, and products and services delivered to external institutions. Highlights were the production of an RPC-based prototype neutron detector and of systems for extracellular measurements for the Bioelectronics & Bioenergy Research Lab of the University of Coimbra (UC). The DL also contributed with technical work and added value to many other LIP groups, including: HiRezBrainPET, ProtoDUNE, HADES, NUC-RIA, ECOTOP, Gaseous Detectors, Dark Matter, RD51, Auger, ATLAS, RADART, Muon Tomography, SND@LHC. The DL collaborated with other external R&D groups, mainly from UC but also from other universities and research centers, in requests involving production or both R&D and production. The work on sealed RPC has started in close collaboration with the RPC R&D group. We started a collaboration with a South Korean research group to develop and build timing RPCs.



REASEARCH INFRASTRUCTURES

Cosmic-rays electronics laboratory (e-CRLab)

The e-CRLab started as a facility dedicated to the development of electronics for cosmic ray experiments and is progressively widening its activities. The focus is put on fast digital electronics implemented in FPGAs (field-programmable gate array integrated circuits). 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.

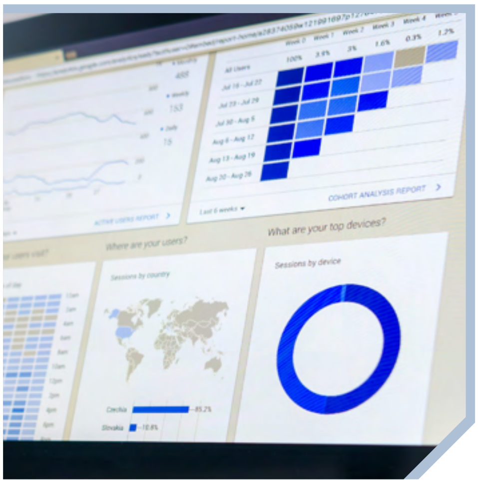
MARTA is an RPC-based R&D project within the Pierre Auger Observatory. e-CRLab developed the electronics and has the responsibility of operations. In 2022 it was finally possible to organize campaigns in Argentina to complete deployment and commission the setups: a hodoscope for precision calibration of the response of the Auger detectors to muons, whose firmware and software are being finalized and tested; and a detector station of the Auger array equipped with RPCs underneath. The systems are expected to become online during 2023. Developments for the control and monitoring of MARTA have been replicated in the tomography system at Lousal. The eCRLab is also involved in the ATLAS upgrade, in particular in the development of electronics for the High Granularity Timing Detector (HGTD): testing the front-end electronics for fast timing and developing auxiliary systems such as DCS and interlock. The laboratory supports the development of electronics and instrumentations for LIP's health and space exploration projects and is involved in outreach and training.

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 2021 the main users of TagusLIP were the LIP CMS group and PETsys. On the LIP side the activities concern the Phase-2 Upgrade of CMS. PETsys leads the consortium Timeof-Flight PET for Proton Therapy, in which LIP is involved, and has the responsibility of developing the readout system.

LIP's Detectors Laboratory and Mechanical Workshop have complementary competences, and many projects at LIP require the services of both facilities. MW and DL now share the same coordination, which is an important step to achieve optimal efficiency.

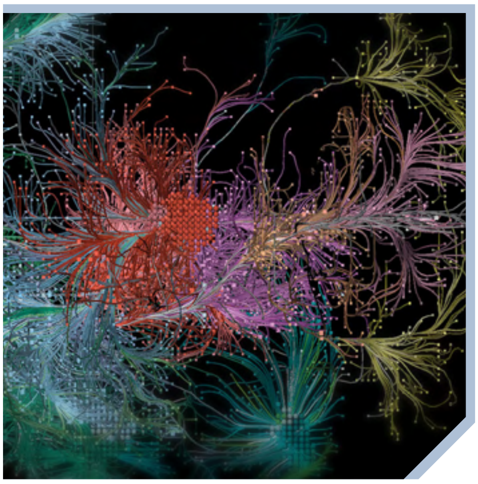


COMPETENCE CENTRES

Monitoring and Control (CCMC)

The main purpose of the Competence Center in Monitoring and Control (CCMC) is to gather the expertise in the design, implementation and operation of monitoring and control systems accumulated by LIP groups in their research activities. Besides facilitating the sharing of this body of knowledge (including sensors, electronics and software) among LIP members, the CCMC aims to establish partnerships or contracts with third parties (e.g., other research laboratories or companies) as a means to transfer knowledge and solutions to the community, including the training of human resources and development of outreach tools.

In 2022 the CCMC continued to collaborate with the ECOTOP group from MARE (UC) on the project for the monitoring of physiological and environmental parameters in the natural habitat of birds. After the development of electronic eggs for measuring heart rate and temperature of nesting seagulls Machine Learning analysis tools started to be developed. They aim at improving the heart rate measurement and associating it with bird behavior features (e.g., stress triggers). LIP and ECOTOP/MARE secured funding from the Technology Transfer Office of UC for the project "MonNest – Nest Monitoring" to develop and build a kit for environmental, physiological and behavior monitoring of nesting birds in cavities, to study the impact of climate change and anthropogenic pressure on the bird population. Additional research was developed in the framework of student research projects, including the development of a non invasive temperature monitoring device with image/target recognition (collaboration with Bosch Aveiro); embedded systems for heating, ventilating, and air conditioning and machine learning in micro-controllers; measuring heart rate and classifying heart sounds, among others.



COMPETENCE CENTRES

Simulation and Big Data (SimBigData)

The purpose of the Competence Center (CC) in Simulation and Big Data is fostering an effective collaboration between the different LIP groups working on such domains and to boost the capability to exploit the existing expertise both internally and externally, towards the academia and industry. The different LIP groups hold a vast range of competences in data science and simulation tools, including physics models, Monte Carlo generators, detector simulation, advanced data analysis, data mining. The ability to fully benefit from such competences requires achieving critical mass, a coordinated training program, the exploitation of synergies between groups and a clear identification of the key areas in which we can contribute in a competitive way. In 2022, two new exploratory projects started: one devoted to machine learning in quantum computing and another in collaboration with the Physics Center of the UM, devoted to the use of machine learning for new materials. The team is also consolidating the experience on anomaly detection techniques in experimental context, where uncertainties play an important role. A close collaboration with the LIP Computing group and INCD has been pivotal to the activities of the CC. The use of containers and the corresponding training of the different teams has gained relevance in the context of data preservation and reproducibility. Along these lines the collaboration with the SPAC group has been enhanced. For the Simulation part, advanced teaching/training and support to the simulation production needs of the LIP groups, researchers and graduate students remain as central tasks. The solid expertise in GEANT4 is complemented by the specific contributions to the GEANT4 collaboration, which will be continued and expanded.

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Knowledge transfer and **societal impact**

Radiation, health and **environment**

Muon tomography

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 in the scientific community at large.

KT at LIP

Strategic areas for LIP's KT are healthcare, space application, data science and digital technologies. 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, Champalimaud Foundation, CHUC, CTN/IST, FCCN/FCT, GHIPOFG, Hospital de Santa Maria, IBEB/ FCUL, ICNAS, ICT/U. Évora, INCD, INESC-ID, INESC-TEC, LNEC, MACC, MARE.

As CERN's reference institution in Portugal and a recognised partner of ESA LIP has a special role in promoting the internationalization of Portuguese companies and to help creating opportunities to increase the industrial return to Portugal. More than three decades of high impact contribution to international collaborations at CERN and in other international scientific infrastructures have proven a successful way to achieve these goals — by proposing partnerships, providing support or facilitating a first contact.

LIP keeps a close connection with the representative of Portugal in the CERN KT forum (José Antão, ANI), with ESA's Industrial Policy Committee representative at PT Space, and represents Portugal in the CERN KT forum for medical applications, in HEPTech, a European Network devoted to KT from large scale HEP science projects and research facilities, and in several European computing infrastructures and initiatives. LIP is a member of PERIN and will actively develop efforts to strengthen the collaborations with this network.

LIP directly involves 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 enhances their level of employability in the private sector and contributes to increase the qualification of the human resources in Portuguese companies.

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Radiation, health and environment

Radon is 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. In the past few years, the work focus was on the measurement of radon in the air and water. The group's main laboratory for the radon study is LabExpoRad, integrated in UBIMedical, the University of Beira Interior (UBI) health technology park. According to European Directive 2013/59/Euratom, building materials must be analyzed for the possibility of exhaling radon gas. our group is developing a system for measuring radon gas daughters inside the container based on low-cost silicon detectors, that can follow the gas buildup inside the chamber in real-time. The group is also actively involved in training in the areas of environmental radiation at graduate and post-graduate level.

Muon Tomography

Muon tomography, a non-destructive imaging technique using the natural flux of atmospheric muons, has had a growing number of applications worldwide in the last decade. LIP has the expertise to contribute to the generalization of the technique locally and to help to establish it as a standard worldwide. The ongoing LouMu project conducts an exploratory muography subsurface geophysical survey to demonstrate the potential of the technique with a well-known target. We explore an existing muon telescope developed at LIP. LouMu is a partnership with the Earth Science Institute (ICT) of the University of Évora and the Ciência Viva science centre at Lousal (CCVL), that houses an underground mining gallery. The telescope is made of 4-RPC planes of 1 m^2, mounted horizontally in a movable structure, that can be tilted up to 30°. A few percent accuracy is achieved in the contrast of the muon transmission images. In 2021, the telescope was optimized at the LIP's DL in Coimbra, while muographing a part of the building. In 2022, the telescope was moved to Lousal, starting the geophysical survey. The first muography showed an image compatible with the expectations from the Corona geological fault crossing the gallery (our main geological target). Full analysis is ongoing. This first surveys of a human-made building and of subsurface geological structure will guide us in the search for applications of muon transmission tomography in follow-up projects, and in the upgrade of telescopes, analyses tools and methods for new requirements.

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) team 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. Below we give an overview of what are the main advanced training event series at LIP and highlight some 2022 events.

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, mainly 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 2022, LIP hosted over 110 graduate students (about 45 PhD and 65 MSC). In 2022 FCT and LIP promoted two calls within the PhD programme PT-CERN. Six grants have been awarded in the first call and seven grants in the second one.

IDPASC school

LIP is a founder of the IDPASC international PhD network. The 11th edition of the school of the IDPASC network, which aim is to train a new generation of high-level experts in the fields of particle physics, astrophysics, and cosmology, took place in Olomouc, Czech Republic, gathering about 25 students.

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) and social events are also part of the program. In 2022 the 7th edition of the LIP/IDPASC student workshop was held in Coimbra in July and the 1st ProtoTera PhD student workshop was held at ICNAS (also in Coimbra) in November.

LHC Physics Course

Consists of close to 20 lectures covering introduction to the standard model, detectors, statistics, and overall research, held from March through May. The course has a final evaluation valid for ECTS credits at IST.

Student awards

Gabriela Oliveira
Gulbenkian "Novos Talentos" grant

Pedro Mendes Pereira
"UMinho Award for Initiation in Scientific Research 2022"

Catarina Felgueiras
"UMinho Award for Initiation in Scientific Research 2022"

Maria Ramos
"Univ. Minho best 2022 PhD thesis award "

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Undergraduate students

LIP Internship Program

The Lab's flagship Internship Program remains active and attractive, benefitting from the ability to systematically improve at each edition. In 2022, the programme's 6th edition counted as always on the broad participation of LIP researchers through the three LIP nodes, who served as project supervisors, delivered tutorials and lectures, guided topical discussions, and attended and contributed to the discussion at the final workshop. Over 50 students completed the program. The overall structure was kept starting with an introduction week in July (lectures and hands-on tutorials) and ending with a two-day workshop in September in which the students presented their work. Common activities were held in hybrid mode. In between, the participants carried out their projects, integrated in LIP's research groups. Mid-term activities involved social get togethers for participants.

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. In particular, LIP regularly participates in events organized by physics departments and 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 and in particle physics and its application in general. In 2022, the following schools and workshops were held:

- 7th edition of the mini-school in particle and astroparticle physics, co-organized by LIP and CFTP: held in hybrid mode (remote lectures and in-person hand-on sessions) and gathered around 20 undergraduate students from several universities.
- Data Science school and symposium, 27-30 June, in Coimbra, an event series focused both in training and in stimulating synergies between fundamental research and industry in data science.

Education, communication and outreach

Education, Communication and Outreach (ECO) are an inseparable part of LIP's societal role. They are also essential for the recognition of the laboratory's impact and for the construction of its future. The ECO team implements, coordinates, and facilitates the laboratory's activities in these domains, encompassing all three LIP nodes. Below, highlights of the 2022 communication and outreach activities are given and LIP's programme for the school community is outlined. LIP also develops equipment for exhibition and demonstration purposes, with the collaboration of its scientific infrastructures and competence centres.

2022 communication highlights

The year 2022 was marked by the start of LHC's Run 3 and the celebrations of the 10 years of the Higgs boson discovery's announcement (Higgs@10). It was also the year in which many of the events successively postponed due to pandemic restrictions finally took place, which resulted in an unusually busy event calendar. An important part of the group's activities are the normal functioning of LIP's communication channels and providing support to the communication needs of the groups. The team produced a small exhibit about LIP and particle physics that was shown in a shopping mall in Coimbra (eight 200x50 cm panels plus the LIP spark chamber) and provided the Portuguese translation of CERN's Higgs@10 poster series, available online. A session on speaking in public was proposed to the participants in the LIP Internship Programme.

Higgs@10

We celebrated the 10 year of the Higgs boson with the screening of the movie "Particle Fever" followed by a discussion, in three occasions and places along the year: In the anniversary day, July 4, at IST, Lisbon; within the European Researcher's Night programme at the main theatre hall in Coimbra; and following the opening of the ATLAS Week in Lisbon, with the participation of ATLAS members, including the spokesperson. The ATLAS week in Lisbon included one more public session: a Universal Science event hosted by Steve Goldfarb (IPPOG/ATLAS) and with a panel of scientists.

Pedro Abreu, LIP outreach coordinator, has received the Ciência Viva Education award in 2022

UN's International Day of Women and Girls in Science

On 11 February 2022, International Day of Women and Girls in Science, we celebrated with a public session in partnership with the astronomy and astrophysics institute IA transmitted via Youtube; and with testimonial videos from LIP female researchers published on social media.

Virtual journey to the Pierre Auger Observatory

An autonomous 3D virtual visualization device of the Pierre Auger cosmic ray observatory was developed at LIP in Minho. The equipment consists of a virtual reality oculus and two commands. The user can viewing in detail not only the landscape but also the detectors and the development and detection of air showers. In 2022 it was officially presented to the collaboration and tested in several outreach events, including a big science fair in Brasilia.

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 Masterclasses and the Teachers Programme at CERN.

IPPOG's International Masterclasses in Particle Physics

At research centres and universities in over 50 countries, high-school students analyse real data from particle physics experiments and discuss their results with scientists at CERN or Fermilab and with participants in other institutions in a videoconference. LIP is the national coordinator of the Masterclasses in Portugal since their start in 2005. Every year the event is held in around a dozen cities all over the country gathering more than 1000 participants. In 2022 the masterclasses were back to in-person mode. During 2022 a new masterclass based on data from the Pierre Auger Observatory was fully developed at LIP. It became an official IPPOG Masterclass in December and will be used in 2023 edition.

CERN Teachers Programme in Portuguese Language

Over the last decade, more than 700 teachers attended the programme, coordinated by LIP with the support of CERN and Ciência Viva. In 2022 the program was back to in-person mode at CERN. It hosted 48 participants: 20 Portuguese teachers, 20 Brazilian teachers, and 8 teachers from all the Portuguese language contries in Africa and Asia, with the support of Instituto Camões.

Ciência Viva Summer Internships

The Ciência Viva Science in the Summer internship programme hosted 8 high-school students at LIP Lisboa for one week full time.

Seminars and other activities in schools

LIP goes to school in several different occasions. Each year, LIP researchers deliver over 50 outreach talks for students in schools and other settings. LIP regularly participates in CV's "Space goes to school" event, with talks delivered by researchers from the different nodes. LIP is the scientific partner of several Clubes Ciência Viva and other science clubs, providing support and activities along the year

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.

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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 Centre (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 - 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, USA
FOV - Field of View
FPGA - Field-programmable gate array (integrated circuit)
FRMII - Research Neutron Source Heinz Maier-Leibnitz
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)

RADART - Radiation Dosimetry Applications to Advance RadioTherapy

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 Centre

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

UA - Universidade de Aveiro

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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