Report from the LIP Advisory Committee meeting

April 27-28, 2023

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Executive summary

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.

Long report

General organization (Jorgen)

Findings

LIP is a research institute organised as a private association with a directorate composed out of members from the universities in Lisbon (2), Coimbra (2) and Minho (1). The Portuguese contribution to CERN is approximately 13M EUR per year and the total funding for LIP 6.5M EUR per year of which 2.7M EUR is project-based and 1.6M EUR core funding. The cost for human resources is about 4M EUR per year. Most Portuguese scientific institutions are struggling for adequate funding. In open competition, LIP collects around 1% of the funding available in Portugal for research. LIP reports frequently to its university partners. LIP makes a great and welcome effort to disseminate the “manifesto” of Mariano Gago to society, which can be considered the backbone of how science policy should be organised in Portugal.

Assessment

The organization of LIP is strong and according to the highest international standards. Its research has a high impact nationally and especially internationally. The sense of innovation is strongly fostered at LIP. Researchers are motivated and supported to seek and explore new thoughts. The international reputation of LIP is outstanding.
All research institutions in Portugal (about 35) are together in a council-like body, but which is not very effective due to the strong competition between the research institutions.
The number of key researchers at LIP without a permanent contract is still too high. This is being addressed by seeking a closer connection with applied research in health, space, computing, big data.
LIP does not communicate directly to policy makers for research and education in Portugal. After their engagement at LIP, numerous LIP researchers continue with their talents in research and industry. At this stage, LIP does not have an organised approach to inform and activate these ambassadors for LIP.

Recommendations

Continuous efforts are recommended to achieve a more effective impact of the council of Portuguese research institutions. The central role of the universities across the research institutions might be important to stimulate, to establish and finally to foster this.
It is recommended to develop a strategy to establish a good balance to achieve high impact in both fundamental and applied research, including for example excellent and wide communication to the scientific community and opportunities for EU funding.

Opening a two-way communication line with policy makers for research and education in Portugal is recommended to establish an open dialogue, including for example opportunities to define and discuss your strengths and challenges.
It is recommended to establish a strong alumni group and program such that they become LIP's informed ambassadors.
It is recommended for small emerging groups (technology and physics) to have a clear short-term plan and verifiable milestones to monitor their progress, especially when they have the ambition to grow to a larger long-term research program. This will give the management some handles to continue, enhance or phase-out certain research directions.
It is recommended that all new researchers hired at LIP should have the ambition (and the support) to apply for a major grant, for example an ERC StG grant.
In general, larger research groups are less influenced by funding oscillations. Accordingly, bringing groups as much as reasonably possible close to each other, might help mitigating the funding uncertainty.

High-energy collider experiments and phenomenology (Jorgen)

Findings

The ATLAS experiment at the LHC

The ATLAS team at LIP performs excellently with numerous scientific achievements and strong recognitions with for example a long list of nominations of LIP researchers for coordination positions. The engagement and impact of LIP researchers in the operations and upgrade aspects of the experiment is excellent. The portfolio of physics research directions ranges from precision measurements to direct searches for new physics, and also heavy ion physics, all in synergy with the performance and reconstruction efforts.

The CMS experiment at the LHC

The LIP CMS group is a stronghold in the international CMS Collaboration. As a highlight, LIP has a leading role in the Precision Proton Spectrometer (PPS) with an outstanding impact in the research portfolio of the international CMS Collaboration. In addition, LIP is involved in the Timing Detector, ECAL, and HGCAL upgrade efforts and a wide portfolio of physics analyses. The involvement in the upgrade with ASIC developments relates to the Portuguese industry.

For both ATLAS and CMS, a challenge to attract postdocs is observed. The success rate of applications in the FCT program is very low (10%) and the timeline between applying and hiring is too long and not sufficiently flexible on the starting date. This is especially important for the transition from one postdoc to another. The Portugal-CERN PhD program (physics and technology) is a good opportunity to attract excellent PhD students.

Phenomenological studies

An enormous evolution of the group is observed from 2018 with 9 FTE to 2022 with 23 FTE. Today this includes 8 ongoing PhD students and 6 ongoing MSc students which is a promising baseline for future developments of the group. The topic is mostly related to QCD (focus on heavy ion physics) and the search for new physics. The FCC pheno accounting is separate from the core pheno group, but in practice both teams do work together. The team

has the ambition to be a significant pheno group in Europe and attracts international collaborators.

Future Circular Collider
The focus of the group is on the FCC-ee which is indeed the main target today in the realm of CERN's Feasibility Study and fits within the European Strategy for Particle Physics. LIP's engagement spans both instrumentation and physics. The involvement is very broad across LIP's groups and universities.

Assessment
The ATLAS experiment at the LHC
The strong appreciation of the international ATLAS collaboration for LIP is demonstrated as well with the organization of the ATLAS week in Lisbon at the occasion of the 30th anniversary of the Collaboration.
There is an increased cost for the upgrade of ATLAS towards the HL-LHC phase, but it is not clear at this stage what the actions are with the FCT to address this.

The CMS experiment at the LHC
The efforts and outstanding expertise of LIP researchers remains highly appreciated in the CMS Collaboration.
There are unclear career prospects for senior physicists in the group with key responsibilities in the CMS experiment.

The interplay of the ATLAS and CMS groups with other technology-oriented and physics-oriented groups at LIP is very well established and the reinforcing effect enhances the impact on the international front.

Phenomenological studies
The pheno group is internationally recognized and therefore on its path to become an important player in Europe, especially also with the growing number of students the groups do attract.
The group leader is re-elected every 2 years which is good for a pheno group.
The group does not cover all physics topics of the experimental groups at LIP, but maybe that should not be the priority of the pheno group in order to reach international impact.

Future Circular Collider
At this stage it seems difficult for PhD students working in ATLAS and CMS to engage in addition to the FCC efforts.

Recommendations
For ATLAS and CMS it is recommended to develop a clear plan with FCT to cover cost increases and cost overruns, including a view on future cost overruns.
The continuation of the Portugal-CERN PhD program is an essential aspect to be established with priority.
It is recommended to prioritize developing career perspective solutions for LIP researchers which are essential for both the institute and the international efforts of the ATLAS or CMS Collaborations.

It is recommended to continue to foster the outstanding relation with the Portuguese industry, especially in the realm of microelectronics which is vital for all current and future experiments in particle physics.
It is recommended to develop a long-term vision for the scope and impact of the pheno group which can be maintained within the resource abilities of LIP.
It is recommended to explore opportunities for synergies between the FCC ambitions and the ongoing ATLAS and CMS efforts, for example by creating procedures for PhD students and postdocs to partially join the FCC efforts.

Structure of Matter (Chris, Werner, Jorgen)

Findings

NUC-RIA (Chris)

The Nuclear Reactions, Instrumentation, Astrophysics (NUC-RIA) Group addresses a range of topics in atomic and nuclear astrophysics through experimentation and modeling. It contributes to the R3B/ FAIR collaboration (Reactions with Relativistic Radioactive Beams) with an RPC-based detector and data analysis of exotic nuclei scattering on protons. At Isolde, the group leads an experiment measuring α- particle scattering on unstable isotopes. Such reactions are relevant e.g., for thermonuclear processes in massive stars. The group undertakes large scale calculations of atomic data required for kilonova modeling.

HADES (Werner)

The group participates in the HADES experiment through the construction and operation of TOF RPCs. This activity builds on the strong RPC expertise at LIP. The first successful application of an increased temperature operation for higher rate capability is an important result. At this moment there is no participation in data analysis for HADES.

Partons and QCD (Jorgen)

The focus of the group relates to participation in the COMPASS and AMBER experiments with a leading role in Drell-Yan physics and expertise in detector control systems. The uncertainty of resources jeopardizes the longevity of the group at LIP because the size of the group might further reduce to below a critical threshold. There are opportunities to explore the interplay with other experiments like ATLAS and CMS. However, the physics interplay might be too weak, and the focus is on partial engagement in AMBER in addition to a long-term engagement in ATLAS or CMS.

NP Strong (Jorgen)

The focus is on spectroscopy (including pentaquarks), structure and ab initio calculations. The last topic is now phased-out because one outstanding team member accepted an offer for a permanent position elsewhere. There is potential for synergies and natural connections with other groups at LIP.

Assessment

NUC-RIA

The group contributes in significant ways to a range of topics, sometimes in a leadership role and is well connected internationally with research partners. Importantly, the research is being pursued through instrumentation, measurements, and computer simulations. The

group has a relatively high number of M.Sc. and Ph.D. students, who are well integrated in the research programme. It has been strengthening its research focus, emphasizing a common denominator: frontier topics in atomic and nuclear astrophysics.

HADES
The plans for the HADES experiment and for FAIR are strongly affected by the Russia-Ukraine crisis. The application of the high temperature operation of RPCs in an experiment is an important activity in order to prove its practical application on a large scale. The activity does not use a significant amount of resources.

Partons and QCD
The participation of LIP in AMBER is not clear, and soon it will be requested to sign an MoU.

NP Strong
The established group at LIP performs excellently with clear and measurable impact internationally. The group attracts international collaborators.

Recommendations
It is recommended, and not only for AMBER, to develop procedures at LIP to establish a partial engagement in another running or future (smaller) experiment in addition to a long-term engagement in running (larger) experiments. This for all career stages.
If LIP decides not to sign the AMBER MoU, a phase-out plan of the project at LIP and a transition plan for the researchers involved is to be established with priority.
With the departure of one key member in the NP strong team, it is recommended to update the long-term vision and strategy of the team.
It is recommended to make the synergy opportunities between the NP strong team with other LIP groups concrete, and for the LIP management to stimulate and support these synergies towards new impactful research actions.

Detectors for Particle and Nuclear Physics (Werner)

Findings
RPC
The LIP RPC group is developing and operating an RPC PET detector and several flavors of TOF detectors for precision timing and precision tracking. High rate operation by increased temperatures of the RPCs was achieved, successful ‘outdoor’ operation of an RPC was proven, an RPC with extremely low gas flow for muon tomography was operated and a sealed RPC detector was successfully operated during a four month period.

Application of these technologies is in the HADES and R3B experiment and is planned for the SND@LHC experiment.

Neutron Detectors
The neutron detector group is focussed on the development of position-sensitive detectors for cold and thermal neutrons based on RPC technology with Boron-10. The target

application is neutron TOF in neutron spallation sources. The goal is fast timing and high position resolution i.e. a ‘4D’ measurement.

Gaseous Detector R&D
The Gaseous Detector R&D group studies drift parameters of electrons and ions in gas mixtures used in the gas detector environment. Specific topics are the study of Xenon properties for the NEXT experiment and the study of negative ions for negative ion TPCs.

Liquid Xenon
The Group is carrying out R&D on Liquid Xenon that is relevant for experiments applying this technology. The present focus is on the application of MPGDs in the Xenon two phase operation.

Assessment
RPC
The LIP RPC group has world leading expertise on the RPC technology, proven by the many results and also by the numerous contributions to the latest RPC workshop.
The successful operation of the RPC-PET prototype, the high rate operation of an RPC at increased temperature as well as the successful operation of a sealed RPC without gas-flow for 4 months represent very impressive results on RPC technology. A key goal in this effort must be the applications of this technology, either in particle physics experiments or also outside this field.

A critical assessment of the RPCs with respect to competing technologies should be performed and the long term goals should be adjusted accordingly. Specifically the competitivity and industry interest in the RPC-PET with respect to crystals+SiPMs as well as the competitivity of the RPC muon tomography with respect to alternative technologies should be critically analyzed. Long term plans should be adjusted accordingly.

Neutron Detectors
The effort builds on the strong expertise on RPC detectors in LIP and represents a natural extension from the classical charged particle detection with RPCs. As for the other RPC applications it is crucial to assess the competitivity with other technologies and it is also crucial to seek genuine applications in experiments.

Gaseous Detector R&D
The group has important expertise and experimental infrastructure for important contributions to the gas detector community. It is important to formulate a consistent plan of this activity within the newly formed ECFA DRD1 collaboration.

Liquid Xenon R&D
The work is not in the framework of an experiment but in the framework of the RD51. There is already a plan to participate in the newly created ECFA Detector R&D groups DRD1 (gas detectors) and DRD2 (liquid detectors).

Recommendations
For the RPC effort it is important to form a consistent plan for the R&D activities with special attention to applicability in particle physics experiments, related fields, medical applications and industry.

In general it is recommended to join the ECFA DRD collaborations for the gas detector and liquid detector R&D in LIP with an elaborated consistent plan.

Dark Matter and Neutrino Physics (Chris & Pier Giorgio)

Findings
Dark Matter (Chris)

Data taken during 2022 established LZ as the most sensitive experiment for WIMP searches, publishing the most stringent limits on spin-independent WIMP scattering cross-sections. The Coimbra group leads several of the most topical searches, e.g., searches for 0v2β decays of Xe-136. It also contributes to the operation of LZ (Detector control and underground monitoring) and to the development of analysis tools. A young Coimbra post-doc was elected to the position of co-convenor of the Data Analysis group.

The LZ group participates in the "Migdal-experiment", which aims to observe the theoretically expected delayed de-excitation of the electrons of the recoil nucleus in a WIMP nucleus collision. Observation of this effect may extend the sensitivity to lower WIMP masses.

The group is taking a major role in establishing a 3rd generation 100 t LXe DM search experiment, a collaboration of the Xe, LZ and Darwin groups.

At present, the group has just one Ph.D. student.

Neutrino Physics (Pier Giorgio)

SNO+ is progressing towards its final goal of searching for 0νββ in liquid scintillator loaded with large quantities of ^{130}Te. The scintillator fill, including flour, was completed in April 2022 and the addition of ^{130}Te is expected to start later in 2023.
The analyses of the water and scintillation fills have refined the understanding of background and produced results on reactor antineutrinos and solar neutrinos.

For DUNE the group has progressed in the design and prototyping of the laser calibration; testing of the proposed system at ProtoDUNE has been affected by delays of the Horizontal Drift detector at CERN.

SND@LHC and SHiP (Pier Giorgio)

SND@LHC completed installation in 2022 and had a very promising start in Run3. Data taking is in progress and the initial analysis is providing results.

The LIP group has contributed to the construction of the detector, its installation and running in. It has been instrumental in test beam calibration of detectors.

The group participates in data taking and plays an important role in data analysis.

For the near future the group is constructing a muon spectrometer to monitor the muon flux: this spectrometer will improve understanding of background, both for present analyses and in view of future upgrades of the detector.

SHIP is pursuing its course in the process of approval and the Collaboration, in which the LIP group has an important role, is looking forward to preparing a TDR.

Assessment

Dark Matter

The LZ experiment delivers world class data on one of the most fundamental issues of particle and astrophysics. Over the years the Coimbra group has steadily increased its impact on the programme for direct WIMP searches, first at LUX, now at LZ. It contributes to all aspects of the experiment, with emphasis on the physics programme. The nomination of a young Coimbra researcher to the prestigious and very competitive position of analysis co-coordinator reflects the very high standing of the Coimbra group within the LZ consortium.

Its participation in the Migdal experiment demonstrates its broad interests and may lead to a further improvement in the sensitivity of the search.

As a founding member of the nascent 3rd generation DM search the group aims to further enhance its leadership role in this field.

Remarkably, the group has managed this world-class involvement despite continued precarious personnel and financial resources.

Neutrino Physics

In SNO+ the group has a leading role in understanding the background in the current scintillation phase and in preparation of the Te phase. In addition it has given a very significant contribution to the analyses of reactor antineutrinos and solar neutrinos.

The group has an ambitious programme of tests to be carried out on ProtoDUNE at CERN, from hardware to DAQ software and to data analysis.

SND@LHC and SHiP

In SND@LHC the LIP group has confirmed and consolidated its contribution to the construction, testing, data taking and analyses.
In particular, the initiative of building a telescope for surveying the muon flux is noteworthy.

The participation in SHIP is a natural extension of the neutrino (and other) physics interests and an opportunity to apply the group's detector experience on a significant scale .

Recommendations
For DM

Evaluate and mitigate the reasons for the relative low level of student participation.

Explore ways at all appropriate levels to achieve a Portuguese participation and contribution to the XLZD experiment.

For Neutrino

DUNE and SNO+ are very visible long range programs providing opportunities for training of students, in design and testing of equipment and in data analysis: the effort to attract students should be continued and enhanced.

For SND@LHC

An active and productive participation in the data analyses of *SND@LHC* is a golden opportunity not to be missed.

Space Applications (Eamonn)

Findings

i-ASTRO

The group continues the lines of activity established over several years, including development of prototype detectors for astrophysical gamma ray polarimetry, a project to place an instrument for terrestrial and cosmic gamma ray measurements on a future European "mini-shuttle", and in-orbit radiation hardness testing of detector scintillator materials. In the framework of the H-2020 AHEAD project, a Compton polarimetry instrument, targeted at a future CubeSat flight, is being prototyped and will be tested soon on a balloon flight. Contributions continue to a proposed NASA mission. Embarkation of the detector materials' radiation hardness experiment on the international space station will happen in 2024.

Space Radiation environment and its effects

The SRE&E group continues in the activity lines established over several years, including contributions to the development of energetic particle instrumentation on space missions, analyses of data from those missions, simulation activities, and radiation hardness investigations. The instrument on board the ESA BepiColombo mission to Mercury is working well, and a very important instrument has been successfully activated on board the recently launched ESA mission to Jupiter, JUICE. LIP is the co-lead for this instrument in the operational phase. The support to the data analyses of these is being funded by ESA in the BARD project. There has been growing interest and activity related to human missions to the Moon and Mars, where radiation issues are important. Simulation tools are being extended and are well placed to address analyses of environments, shielding strategies, and effects. In addition, a radiation competence centre is proposed.

Assessment

i-ASTRO

Progress continues to be very good. Participation in the US AMEGO project continues and while adoption of the mission by NASA is not guaranteed, it is a strong candidate. Should it be adopted, the group has some assurance from the Portuguese Space Agency that the group's contributions would receive the necessary funding. The participation in the EU AHEAD project is healthy and very complementary, with a balloon flight soon, as a precursor to a potential CubeSat mission. ESA's "mini-shuttle" – SpaceRider, the next-generation reusable automated transportation system – was approved to proceed and has a strong Portuguese participation including development of the landing site in the Azores. The group took advantage of the excellent opportunity to embark a gamma ray detector with dual use: during earth-pointing mission phases looking for atmospheric gamma rays (TGFs), and during space-pointing looking at cosmic gamma rays. Facility equipment quality is identified as a weakness.

Space Radiation environment and its effects

The group has achieved great success in implementing its energetic particle instrumentation and radiation effects experiments in space. With instruments simultaneously measuring particle environments at multiple locations in the heliosphere, unique opportunities arise for science and mission-related environment assessments. There is some funding in place to support this, but it is probably inadequate and, in any case, will need to be extended to cover the missions' lifetimes. Apart from this, the group shows considerable ambition, and the activities outlined are very topical and important. For example, the human spaceflight plans of ESA undoubtedly imply much radiation-related work The group recognises that funding and "staffing" are problems, and these may limit what is feasible. Notwithstanding this, the group continues to grow in stature internationally. The group has a very

collaborative nature and the idea of establishing “RADLIP” - a collaborative Radiation Competence Centre for LIP is welcomed and will add to LIP’s attractiveness for future projects.

Recommendations

i-ASTRO

In i-ASTRO, the Advisory Committee recommends continuing active engagement with the Portuguese Space Agency and FCT in order to ensure that resources will be available for the future phases of several activities, including facility improvements. As the group reports, funding is a potential problem. Therefore, in the reporting to the Advisory Committee, activities’ funding status (confirmed, requested, to be requested) should be clear. Perhaps the idea of the “*Radiation Competence Centre”,* mentioned during the review, could leverage an improvement in the standard of equipment. Care should be taken not to overstate TGF health hazards.

Space Radiation environment and its effects

For SRE&E, the main problems are funding and attracting students. It is difficult to see what more can be done since the group is already working proactively on solving these problems. ESA should be very interested in the evaluation of muti-point measurements in the heliosphere, and ultimately in the development of models of the Jovian environment. We recommend that the group continues proactive interactions with several groups at ESA: the Space Environments and Effects group where funding might be found for environment modelling activities (e.g. solar energetic particle (SEP) helio-radial/longitude variations, and statistics); the Science directorate where a Heliospheric Working Group has recently been established which would undoubtedly welcome LIP contribution (e.g., shock interactions with GCRs and SEPs); and the components radiation effects group, already host to a research fellow from LIP. The group should also carefully assess possible EU funding opportunities. The radiation competence centre proposal should be taken forward.

Advanced and Distributed Computing (Karoline)

Findings

The LIP team provides scientific computing and data processing services internally, to the wider Portuguese research community, and as part of international scientific e-infrastructures and initiatives (WLCG, EGI, IBERGRID and EOSC). As part of the FCT Roadmap of Research infrastructure, LIP coordinated all technical activities of the Portuguese National Distributed Computing Infrastructure (NDCI). This included provision for an impressive range of scientific communities, such as Earth science and biodiversity

research. Last years recommendation to merge the Advanced Computing and the Distributed Computing and Digital Infrastructures groups has been followed.

Assessment
Given its number of researcher / engineer members relative to the number and scale of tasks the group is highly efficient and effective. The important role of LIP's computing group has continued to play a large and further increasing role on the national level of computing infrastructure. The service provided by the group to LIP teams and to the LHC community has been outstanding. The LIP group has continued to be very successful in securing project funds from Portuguese and from European sources. In R&D alone, four new European projects started in 2022. Maintaining a sustainable work level for group members is difficult with many activities being supported on a voluntary basis.

Recommendations
The group provides a critical service to LIP and to the Portuguese research community. Limited funding from national sources for upgrading aging hardware is a recurring problem, endemic to IT technology, as is the recruitment of skilled staff. The group's involvement in national and international consortia is a good strategy for maintaining the level of funding on the required high level.

Research Infrastructures and Competence Centers (Miguel, Pier Giorgio, Karoline, Werner)

Findings
Mechanical Workshop and Detectors Lab (Miguel)
Both the Mechanical Workshop and the Detector Lab are integrated in most of the research topics of LIP, seeing their support and contributions in most of the talks. The teams are highly motivated (up to 6 years working together) and experienced. For the Detector Lab, the level of involvement, up to 85% with LIP Research is remarkable, somehow lower for the Mechanical Workshop with 60% of its activities with LIP group's. To be noted, all objectives and deliverables have been completed in 2022, also a remarkable achievement.

LOMaC (Miguel)
The LOMaC Laboratory has very challenging contributions to the ECFA Detector R&D Roadmap DRD6, positioning LIP in a visible position for the future detectors (FCC).

TagusLIP (Pier Giorgio)
Test to validate the TOFHIR chip coupled to sensor modules (for the Barrel Timing Layer of CMS in view of the Phase II upgrade) have shown performance as expected. A first batch of chips has been ordered.
TagusLIP is moving to new premises, to accommodate the business growth of PETsys. New lab equipment has been ordered by PETsys, which will also benefit LIP.

Simulation and Big Data Competence Centre (Karoline)
The purpose of the Competence Center (CC) on Simulation and Big Data is fostering an effective collaboration between the different LIP groups working on these areas and to boost the capability to exploit the existing expertise both internally and externally, towards academia and industry. The core activity in Big Data continues to be the use of machine

learning techniques for the different data analyses done by different groups at LIP, with ATLAS, LZ and SWGO being currently the most active ones in this context. In Simulation, LIP is continuing its participation in the GEANT4 collaboration and contributes to improvements for the new releases. The training of students and researchers in simulation and machine learning continues to be a core activity.

Competence Center in Monitoring and Control (Werner)
This competence center is a transverse activity in LIP that gathers expertise in the area of monitoring and control systems. Training as well as construction of instruments for outreach are also important activities of this group.

Assessment

Mechanical Workshop and Detectors Lab
From the different presentations, the workshops and laboratories have the appropriate size and competences to respond to the early needs in prototyping and demonstrators.

LOMaC
The main objectives are to pursue some cost-effective production of tiles with high performances on radiation harness, objectives which are achievable for LIP, in collaboration with other partner's Institutes.

TagusLIP
Meeting the ambitious specifications of the latest version of TOFHIR confirms a long record of high quality chip designs produced at TagusLIP

Simulation and Big Data Competence Centre
Beyond any doubt, SIMBIGDAT is of great value to all LIP groups. The importance of machine-learning techniques cannot be underestimated, and SIMBIGDAT is a very cost-efficient way of channeling ML knowledge to and between the research groups.

Competence Center in Monitoring and Control (Werner)
This activity brings together both the expertise and human resources from several LIP groups (ATLAS, DUNE, LZ, IT) and uses the accumulated know-how. This is seems to be a very efficient way to use this expertise across the LIP activities.

Recommendations

Mechanical Workshop and Detectors Lab
Ensure that the external revenues generated by the increasing support to externals are used to maintain the high level of infrastructures in the Mechanical Workshop and Detector Laboratory, in complement of the recurrent operation budgets. Whenever possible, also favor the highest level of collaboration between the two centers of competences, evaluating internal mobilities (exchange of personnel) to face single points of expertise.

LOMaC

Some concerns have been raised about aging equipment and need for replacement and upgrades with re-equipment to stay at the forefront of the technologies.

Simulation and Big Data Competence Centre
As the field of machine learning is developing very rapidly, the group should make sure to keep up to date with the most recent developments. This could be done, for example, through links to existing and future research centers in the field of ML such as CESGA, the high-performance computing center in Galicia.

Competence Center in Monitoring and Control (Werner)
Ensure that the planned projects are compatible with the existing personnel, specifically ensure that one does not enter in R&D activities where commercial solutions exist.

Health and Biomedical Applications (Katia)

Findings
LIP has further consolidated its research and development in novel medical imaging and high-resolution dosimetry instrumentation for applications in diagnostics, image-guided radiation therapy and radiobiology. These activities are carried out under the overarching research theme of "Advanced Radiotherapy and Charged Particle Therapy Applications" by two research groups, the *Orthogonal Imaging for Radiotherapy Improvement group* (ORIMAG), based in Coimbra, and the *Radiation Dosimetry Applications to Advance RadioTherapy* (RADART), based in Lisbon. Most of the activities of these groups are carried out with the support of national/international funding and in the framework of undergraduate thesis works.

ORIMAG
The ORIMAG group investigates new techniques for in-vivo verification of radiotherapy treatments with therapeutic X-ray beams (OrthoCT project) and protons (O-PGI and in-beam time-of-flight [TOF] positron emission tomography projects). This is pursued through extensive Monte Carlo simulations and first prototype systems aiming to exploit the gamma radiation produced during therapeutic irradiation through scattering of X-rays (OrthoCT) or as a by-product of nuclear reactions undergone by the primary proton beam (O-PGI and in-beam TOF PET).

RADART
The RADART group aims to support analysis and interpretation of pre-clinical and clinical studies in forefront radiotherapy modalities. This is pursued experimentally through the developments of new detectors and materials for high-resolution dosimetry, and computationally by trying to elucidate the physical and physicochemical effects underlying the favorable radiobiology of recently proposed new radiotherapy modalities such as FLASH radiotherapy and minibeam therapy.

Assessment
ORIMAG

For the OrthoCT project, a promising proof-of-principle experiment with a prototype system was already performed in the previous reporting period at the Radiotherapy Department of the Coimbra University Hospital Center, but publication of the results is still outstanding due to lack of manpower and funding. For the other two projects, which are still receiving funding, the activities of the group have been primarily focused on Monte Carlo simulations. For the O-PGI project, the thorough simulation studies which were committed in the last reporting period could be successfully performed and a small prototype system is being assembled for experimental testing foreseen in fall 2023. For the PET project, the simulation activities of the group supported the realization of the in-beam TOF PET scanner currently under commissioning in Austin. Moreover, the group contributed to the project with a very valuable acceleration/validation of the computational framework which will be needed for implementation of a workflow of treatment verification using the newly developed scanner.

RADART
In terms of new materials and detectors capable of measuring energy depositions at micro- and nanometer scales, the group developed prototypes based on scintillating plastic optical fibers, already tested in some radiation qualities, and nanometric sized polystyrene fibers, still at the production optimization level. In the area of Monte Carlo simulations, the group developed and validated different computational tools to study different effects involved in the postulated improved therapeutic index of different new frontier radiotherapy modalities, benchmarking the results with available experimental data made accessible through national and international collaborations.

Recommendations
Most of the new lines of research started in the last few years have been motivated by the establishment of the ProtoTera Association, which supported intensive activities in the scope of advanced radiotherapy and particle therapy, including a dedicated FCT doctoral Programme coordinated by LIP. Despite the current undefined situation on the future of charged particle facilities for cancer therapy in Portugal, LIP remains committed to its mission to push forward an International Network for Advanced Radiotherapy, leveraging the already established network of cutting edge collaborators, e.g., in France and in Germany. Moreover, the creation of a Radiation Engineering Centre at LIP for advanced training in the application of ionizing radiation to different fields (health, materials, and space) is being considered and should be carefully evaluated, taking into account synergies with meanwhile existing overarching infrastructures (e.g., competence centers). The committee congratulates the different groups for their achievements and their success in establishing valuable collaborations with world-class institutions and researchers. Moreover, they encourage timely publication of the results achieved, as this can be crucial to the securing of funding and raising interest in the community. However, the committee also shares concerns related to the current status of the ProtoTera initiative, and supports the efforts of the LIP governance to develop a proper strategy aiming to maintain a competitive research program within the available local infrastructures and resources, e.g., by strengthening the already established international networking and exchange platform with cutting edge institutions, and exploring collaboration opportunities with the several proton therapy centers currently planned in Spain.

Computing – Social Physics and Complexity (Karoline)

Findings
The SPAC (Social Physics and Complexity) group joined LIP relatively recently, in 2021. Broadly, the group addresses societal challenges, such as disease forecasting, human behaviour, and public policy, using computational tools and complexity science methodology. SPAC's work is mainly funded by an European Research Council (ERC) Starting Grant to the group's PI to conduct the research project "Fake News and Real People – Using Big Data to Understand Human Behaviour (FARE)". In 2022, SPAC was furthermore awarded an ERC Proof-of-Concept grant (FARE_Audit) to develop an auditing tool for search engines. In 2021, the group focused on team building (which is particularly important given its interdisciplinary nature), and on establishing the computational and data infrastructure for its research. The group has successfully completed this stage and is now fully operational. In 2022 SPAC has continued research on the COVID pandemic and its support of the Portuguese health authorities in their pandemic control efforts and in other health related questions such as antibiotic over-prescription. SPAC has had a repeated presence in the Portuguese media

Assessment
The group is working on hot-topic areas (epidemiology, social media, ethics and privacy) with no lack of novel and innovative ideas. The group has an excellent track record of securing national and international competitive funding and attracting international young talent. Furthermore, SPAC is a flagship of public engagement for LIP. The inclusion of the SPAC into LIP has turned into a successful experiment. There is a mutual appreciation of the previously existing LIP research groups and the newly added SPAC group. SIMBIGDAT is a valuable partner of SPAC.

Recommendations
In the coming year the focus should be on strengthening ties to similar activities on the international (EU and otherwise) scene and on increasing the group's visibility internationally. Furthermore, the acquired funding should be converted to peer-reviewed publications. The very positive reception of SPAC into LIP now needs to be put on a more solid scientific foundation. All sides should actively strive to form a scientific case for the presence of SPAC at LIP. SPAC should continue to access SIMBIGDAT for scientific computing needs.

Science and Society (Katia, Werner, Chris)

Findings
Radiation, Health and Environment (Katia)

The group focuses on radiation measurements indoors and outdoors, developing affordable solutions for radon detection and studying bioremediating properties of plants. Moreover, it continues the efforts in setting up a National Radiological Network, in collaboration with the Portuguese Environment Agency, in view of establishing national radiation maps relevant for public health.

Muon Tomography (Werner)
A muon tomography experiment using RPCs was successfully conducted in the Lousal mine. Tests on other structures (e.g. buildings) are planned.

Advanced Training (Chris)

LIP has an ambitious and successful student training programme. Presently it counts 64 Master and 54 Ph.D. students, 33% being female. This is achieved through “master classes'', Internships, Summer Courses, dedicated lecture programmes and University teaching. Some of the funding for the Ph.D. programmes risks being terminated.

Education, Communication and Outreach (Chris)

Following the COVID pandemic the group resumed a wide-ranging spectrum of activities, sometimes in collaboration with national and international partners. Projects at High Schools were relaunched. Major events were staged (Women’s Day in Science; 10 Years of Higgs discovery; etc.). Talks at high schools reached thousands of students. New Outreach material (cloud and spark chambers, Geiger counters) was fabricated. Members of LIP are co-chairs of IPPOG (International Particle Physics Outreach group), the EPPCN (European Particle Physics Communication Network) and the CERN Forum for High school students and teachers.

The LIP co-chair of the IPPOG received the 2022 Ciência Viva Education prize.

The group wishes to further enhance and widen these activities by involving additional members of LIP.

The small Communications group has formulated and subsequently adjusted its communication strategy. The group maintains the LIP Web and edits the excellent yearly reports. LIP is very present in the Social Media, through many interviews, and newspaper articles. Communication between the LIP nodes works well. LIP realizes that it has become crucial to enlarge communication with the full scientific Portuguese community, the Portuguese industry, the Funding agencies, and the political decision makers. A good example is the re-edition of the “Manifesto para a Ciência…” of J. M. Gago and its public presentation at the three LIP nodes.

Assessment
Radiation, Health and Environment

Good progress continues to be made by a very expert team but with limited human and financial resources. However, it can be reiterated that this work is only useful, if it is embedded in a national infrastructure making the measurements authoritative and publicly available for further action. The drive to establish such a national Network is essential and very laudable.

Muon Tomography

The principle of muon tomography is established since a long time. The successful operation of RPCs at very low gas flow make them a viable technology for this application. It is important to establish the relation of this RPC based implementation of muon tomography to other technologies as well as other geophysical methods. The interest and support from this community has to be verified.

Advanced Training

The Board congratulates LIP to its success in attracting students. This is due to the enthusiastic commitment of many of the senior researchers and professors at LIP. Educating and training so many students in the demanding, competitive and international environment of particle physics technology and research represents an enormous return of investment by the Funding Agencies and an important contribution to Society. While the supervision of students has been improved in recent years, a programme of "mentorship" would further strengthen the development of the students. The threat of termination of some of the programmes (CERN-PT Ph.D. programmes) is a real concern. The Board feels that the value of student training – intellectually, economically and financially – needs to be more explicitly explained to the relevant Authorities.

Education, Communication and Outreach

LIP has a world class education and outreach program. The breadth and multitude of activities and initiatives is outstanding, given the relatively modest resources. Further development would of course be very desirable and possible, if most, if not all of LIP personnel would contribute.

The Communication group is very (pro)active. The programmes communicating with the schools and the physics community work very well. The Advisory Board supports the view of the LIP management that communicating with all levels of Society has become crucial to improve the awareness of LIP and its importance to Society.

Recommendations

Radiation, Health and Environment

The committee commends the progress made and the securing of funding for an international advanced training of students on radiation protection issues and measures. However, the committee would also like to reiterate the recommendation to the LIP management to contribute to making the National Radiological network a reality.

Muon Tomography

Establish the relation of the RPC solution to competing technologies. Join the ECFA DRD1 collaboration in a consistent fashion together with the other RPC and gas detector activities.

Advanced Training

Consider implementing a “Mentoring Programme” for M.Sc. and Ph.D. students

Develop and communicate a document, detailing the benefits of student training at institutions like LIP, addressing the intellectual and financial benefits to Society, the Portuguese industry, and the Funding Agencies.

Education and Outreach

Provide a list of topics to which additional LIP personnel could be attracted and contribute aiming to further widen the education and outreach programme.

Communication

The Board suggests developing a broader communication strategy and reviewing the required resources to match the needs for communicating with the increasing number of partners to be addressed.

Cosmic Rays (Masahiro)

Findings

AMS

LIP has been part of the Alpha Magnetic Spectrometer (AMS) international collaboration since 1998. AMS-II is installed at the ISS and has been taking data since 2011. Since then, a huge data set has been gathered continuously, with over 45 million events per day. LIP is responsible for RICH operations, monitoring, characterization, and the algorithms used to reconstruct particle properties. AMS provides a new and very precise view of cosmic rays. The LIP group makes an essential contribution to the RICH data analysis. Specifically, the group has been studying isotope compositions (proton/deuteron and 10B/11B) and the seasonal variation of cosmic rays, such as correlations with the solar rotation and magnetic reversal cycle. This information contributes to understanding the solar system's cosmic ray flux and magnetic field structure.

Auger

LIP participates in AUGER, the world’s largest ground-based detector array for studying ultra-high energy cosmic rays, with physics analyses and detector upgrades. The LIP team focuses on understanding the physics of the first hadronic interaction at the highest energies by studying the muon component in air showers. The LIP team has strong competence in air-shower physics and is coordinating the efforts in this area. LIP participates in the upgrade by leading the MARTA project, aimed at installing RPCs under the water tanks of a subset of the Auger array to improve the muon measurement: this will permit detailed shower studies at lower energy. After the pandemic, the installation and commissioning of the MARTA chambers are expected to be done. The study of quark-gluon plasma was conducted in collaboration with members of LIP’s phenomenology group, and this new class of models has the potential to solve the muon puzzle, which accelerator experiments shall verify.

SWGO
For some years, LIP has promoted the idea of a gamma-ray observatory covering a broad energy spectrum in the southern hemisphere. The idea has materialized in the SWGO international collaboration, which is preparing a proposal. Currently, LIP is working on engineering the water Cherenkov and simulation of its performance. Simulation and analysis are ongoing for the whole array to understand the physics performance.

Assessment

AMS
The LIP team in AMS is small, but its contributions to software and the analysis of isotope compositions and seasonal variations are very significant.

Auger
The LIP team has fulfilled its engagements in producing software, now being used by the Collaboration and continuing and refining the air-shower analysis, and its long-term effort to solve the muon puzzle is highly appreciated.

SWGO
The drive of LIP in promoting this research is recognized by the positions of some LIP staff in the management of the Collaboration. The contributions to engineering design, performance software, and potential physics studies are outstanding.

Recommendations

AMS

AMS will observe the flip of the solar magnetic field in 2023. The Committee considers this a golden opportunity for a strengthened LIP team to harvest its investment in seasonal CR variations, which should be noticed. SAB recommends stable and continuous observation and data accumulation over the entire solar cycle of 22 yrs.

Auger

The LIP AUGER team should concentrate on precisely measuring and analyzing the muon component with the MARTA array. The Committee considers LIP to be in an exceptionally advantageous position to contribute to understanding the physics of hadronic collisions, which could become the legacy contribution of AUGER. It encourages LIP Management to establish a stronger focus on this subject and make it a strategic effort.

SWGO

The Committee recommends continuing the efforts to prepare a convincing scientific, technical, and funding proposal. The activity for the study of the neutral particle (photon) search in Auger will be beneficial for the design study of SWGO and supported.