CNRS/IN2P3 and the Helmholtz Research Field *Matter*: A new International Research Laboratory

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ABSTRACT A new International Research Laboratory for the fields of particle, astroparticle, and hadron and nuclear physics in Germany, jointly managed by CNRS/IN2P3 and the Helmholtz Association, will focus on a selected number of highly relevant scientific and technological topics, where together CNRS/IN2P3 and Helmholtz can make a distinctive difference within the next 5-10 years. These core topics — among them dark matter experiments and innovative accelerator technologies — will be complemented by the "transverse topics" computing and data science, detectors, theory, and radiation physics. These will prove useful for all main IRL topics.

1 INTRODUCTION

Following the *Letter of Intent* (LoI) signed on 12 February 2019 by the President of the CNRS, Antoine Petit, and the President of the Helmholtz Association, Otmar Wiestler, discussions were initiated to strengthen the cooperation in the area of high energy physics, hadron&nuclear physics, astroparticle physics, and in associated technological developments in accelerators, detectors and computing research. On 14 February 2020, the LoI was extended until 30 June 2021.

As visible signs of this intended stronger collaboration between the two research organisations, concrete research structures are proposed:

1. An application for a *Helmholtz International Laboratory* (HIL) with a focus on gravitational waves and multi-messenger astro-particle physics has been submitted, with participation from IN2P3 on the French and KIT, DESY and GSI on the German side.

2. Plans for a topically broader CNRS *International Research Laboratory* (IRL) are being developed, following — among others — discussions between Joachim Mnich (DESY) and reynald Pain (IN2P3).

In the following, first the concept of an IRL is introduced and the partners of the IRL are described. Scientific and technological topics foreseen for the new structure are discussed next, followed by a short overview of the next steps.

2 INTERNATIONAL RESEARCH LABORATORY AND PARTNERS

2.1 CNRS/IN2P3

The CNRS (*Centre National de la Recherche Scientifique*) is the major French research organisation, tasked with fundamental research. It is composed of a number of institutes, among which IN2P3 is charged with the topics of particle physics, astroparticle physics, hadron&nuclear physics and the associated instrumentation and computing technologies.

IN2P3 laboratories in Paris, Palaiseau, Orsay, Marseille, Nantes, Strasbourg, Caen, Lyon, Bordeaux, Clermont and Grenoble have proposed projects for the new IRL.

In addition to the research carried out by labs located in France, the CNRS/IN2P3 has has the possibility to create labs abroad with foreign partners. One recent example is an IRL joint with the University of California at Berkeley and LBNL. This IRL, the Center Pierre Binetruy, carries out research on cosmology.

2.2 Helmholtz Research Field *Matter*

The Helmholtz Association is Germany's largest research organisation and addresses fundamental and applied research questions with high impact for society. Its Research Field *Matter* bundles the research related to the structure and the functions of matter. It is organised in three programs, two of which are relevant for the proposed IRL: The program *Matter and the Universe* comprises all activities in particle, astroparticle, and hadron& nuclear physics, and *Matter and Technologies* covers scientific computing, accelerator R&D as well as detector R&D.

Matter research is carried out in nine Helmholtz centers. Of these, the four centers DESY, GSI, Jülich and KIT have proposed projects for the intended new IRL.

2.3 The International Research Laboratory

An International Research Laboratory is a laboratory that is established, by CNRS, in a foreign country with the aim of strengthening the French collaboration with researchers and institutions of the host country. Technically, an IRL works in a way similar to a CNRS laboratory in France. In particular, CNRS personnel can be delegated to an IRL in order to carry out research in the host country. IRLs are CNRS entities which can be carried either by one or several institutes of the CNRS. They are created for initial periods of five years, with the option of extensions by further five-year periods upon agreement by all involved partners. The management of an IRL is handled jointly by the partners, which nominate the director and co-director of the structure. As a basis for the work, a *memorandum of understanding* (MoU) needs to be negotiated between the partners, in this concrete case between IN2P3 representing CNRS and a center acting on behalf of the Helmholtz Association.

Organisationally, an IRL is a single lab with a unique administrative centre. The various research activities of the IRL, however, can be distributed over various sites in the host country. DESY proposes to act as the central laboratory on the Helmholtz side.

3 THE TOPICS OF THE IRL

The intended strengthened Franco-German collaboration in general, and the proposed IRL in particular, will focus on topics of high scientific relevance in fields in which the involved French and German scientists have leading positions and where high impact over the range of a few years is to be expected. These topics have emerged in several discussions over the last two years:

- beginning of 2019: preliminary list of activities (Andreas Haungs, Dirk Zerwas);
- summer 2019: meeting at KIT with Johannes Blümer, Klaus Eitel, Stefan Bekavac, Manuella Werp, Andreas Haungs (Helmholtz) and Patrice Verdier, Thomas Palychata, Dirk Zerwas (IN2P3);
- September 2019: meeting at LPNHE Paris of representatives of the four Helmholtz centers with the IN2P3: Johannes Blümer, Klaus Eitel, Manuella Werp, Stefan Bekavac (KIT), Hans Ströher (Jülich), Yvonne Leifels (GSI), Thomas Schörner (DESY), Reynald Pain, Patrice Verdier, Berrie Giebels, Volker Beckmann, Laurent Vacavant, Thomas Palychata, Dirk Zerwas (IN2P3).

In addition several meetings have been held between KIT (on behalf of Helmholtz) and IN2P3 for the preparation of the HIL.

Concretely, the envisaged topics are the following:

1. dark matter;
2. innovative accelerator concepts;
3. gravitational waves with a view towards multi-messenger astroparticle physics.

In this paper, we only touch very briefly topic 3) “Gravitational waves” in the appendix, since it forms the central part of the HILAGRO HIL proposal to Helmholtz.

The above-mentioned scientific topics will be supplemented by a set of supporting technological and/or methodical *transverse topics*:

A. computing and data science;

B. detectors;

C. theory physics;

D. radiation physics.

The definition of the topics does not claim to be complete nor to be fully orthogonal.

3.1 Topic 1: Dark matter

According to our current understanding, roughly 20% of our universe is made of yet unidentified gravitating particles, so-called *dark matter*. Numerous models of “new” or “beyond Standard Model” (BSM) physics comprise hypothetical dark matter candidates, and dark matter is the objective of many experimental efforts in particle physics (e.g. at the Large Hadron Collider LHC or the KEK’s Belle II experiment) or astroparticle physics. The proposed IRL will focus on the following activities and experimental approaches in which both the French and the German side are heavily involved — where it should be noted that theoretical physics plays an important role for many activities in this field of research:

- DARWIN is a cryogenic liquid-xenon dark matter search experiment that builds on the Xenon experiment and is supposed to be realised at LNGS. It will significantly improve the sensitivity with respect to previous and current experiments. KIT, Subatech Nantes, LPNHE and IJCLab Orsay are strongly involved in the preparation of the experiment.
- Axions may possibly provide viable dark matter candidates that can both satisfy astrophysical requirements and solve the strong CP problem. They are searched for in numerous experiments, and especially DESY is currently building up a strong experimental axion search programme, consisting of the experiments ALPS II, BabyIAXO/IAXO and MADMAX.
- JEDI/CPEDM: Measuring the electric dipole Moment (EDM) is an indirect way of constraining new phenomena. The particularity of this experiment at Jülich, which aims at studying the EDM of charged particles, is that the accelerator itself is also the detector.

3.2 Topic 2: Innovative accelerator concepts

Accelerators are indispensable tools in many fields of science, technology, and society. French and German institutions — not least IJCLab (formerly LAL and IPNO), LLR, DESY and KIT — have since many years driven accelerator R&D, and also today they are at the forefront of research. One important topic in accelerator R&D is the increase of the accelerating gradients, with the aim of both reducing the size (and thus the cost) of future accelerators and of achieving higher beam energies (and thus centre-of-mass energies in colliders). Another objective is increasing the quality factor Q of accelerating cavities. Several approaches are pursued by both IN2P3 and Helmholtz and will become activities of the IRL:

- An important goal are improvements in the material treatment and manufacturing process of “standard” superconducting radio-frequency (SCRF) niobium cavities as used in the European XFEL and also foreseen for the European Spallation Source ESS or the intended International Linear Collider ILC. Various recipees e.g. for thermal treatment of the cavities, are pursed, and both IN2P3 and Helmholtz are leading several efforts in this direction.
- Another direction are steps towards the miniaturisation of accelerators using new acceleration technologies. One innovative approach is plasma wakefield acceleration (PWA) — a technique that promises a 100-fold decrease of accelerator sizes as compared to the SCRF machines mentioned above. The PWA technology awaits its first application for purposes that require only low energy and low beam current. A future use of PWA for high-energy physics is still farther away. The EU project EUPRAXIA, to which both CNRS and DESY contribute, bundles numerous activities in the field of PWA research.
- CPEDM/JEDI: At the Jülich storage ring COSY, important studies towards dedicated future storage ring searches for charged-particle EDMs can be performed.

4 TRANSVERSE TOPICS

The topics of the IRL all rely on innovative techniques and technologies, a number of which will be pursued in dedicated transverse topics.

4.1 Transverse topic A: Computing and data science

Scientific computing and data science are increasingly important for any kind of science, and the research fields from which the proposed IRL is formed have always been at the forefront of big data management and data analytics. The following activities will be particularly pursued within the IRL:

- Big data management: All branches of science represented in the IRL produce large amounts of data that need to be collected, stored, made accessible, and analysed. Data management and collaboration between different Tier centers will enhance the efficient use of resources. Of increasing importance is the treatment of data according to the FAIR data principles (“findable, accessible, interoperable, reusable”), and in particular the questions of open data and meta data treatment.
- Data science - studying tools and methods of machine learning and artificial intelligence: A particular focus is on the applications such as GANs (generative adversarial networks) and others to concrete problems in the topics of the IRL.
- Machine learning, in particular in theory and phenomenology: Machine learning as a technique has become a more and more important tool used in the most varied branches of science. A new development is the use of these techniques for theoretical questions, one particular example is using GANs in event generators for particle physics interactions.

4.2 Transverse topic B: Detectors

The detectors of today's experiments in particle, astroparticle and hadron&nuclear physics typically work at the technology frontier. French and German scientists involved in the IRL are deeply involved in generic detector R&D and aim at employing new developments first on small scales, as proof of principle and demonstrator, before using it at larger scales. The following activities will be implemented in the IRL:

- Tracker developments: HVCMOS detectors and generally silicon trackers for high precision tracking are key elements for future experiments. They are pursued at both French and German institutions contributing to the IRL, both on a basic R&D level and, e.g., in the construction of tracker end-caps for the upgrades of the LHC experiments ATLAS and CMS.
- Calorimetry: Highly granular calorimetry enables powerful reconstruction algorithms such as particle flow. Additionally, a renewed interest in time-of-flight information has emerged, thanks to impressive progress in precise timing measurements. Leveraging these developments is crucial for future experiments. An example for basic R&D that is to be carried to large-scale endeavours is the application of CALICE technology to the CMS HGCAL upgrade.
- Cryogenic detectors are an essential technology for direct dark matter search experiments. Germanium detectors operated at low energies are being developed for experiments at GSI.

4.3 Transverse topic C: Theoretical physics

Theory and phenomenology play a special role in the IRL, as they do in the entire research fields of particle, astroparticle and hadron&nuclear physics. Theory and phenomenology develop models, thus pointing the way to future experiments; they interpret experimental results; and with their inherently interdisciplinary approach they connect activities in the IRL to each other and to ideas from outside the immediately involved research fields. A prime example is the search for dark matter, which relies on complementary approaches from different research directions and experiments, not all of them represented in the IRL.

4.4 Transverse topic D: Radiation physics

Applications of particle accelerators in different fields can be part of the program. Of particular interest is the application of high intensity beams at FAIR in the field of particle therapy.

5 NEXT STEPS

The IRL will become a cornerstone of CNRS–Helmholtz collaboration, together with the proposed HIL on gravitational wave physics, which on the Helmholtz side is managed by KIT.

To realise the proposed IRL, the following next steps will be taken:

- For the preparation of the IRL MoU, DESY has proposed to take over the negotiations on behalf of the four involved Helmholtz centres (DESY, GSI, Jülich, KIT).
- A French-German IRL director pair needs to be nominated.
- The official start of the IRL is foreseen for 1 January 2021.

A GRAVITATIONAL WAVES WITH A VIEW TOWARDS MULTI-MESSENGER ASTROPARTICLE PHYSICS

The following activities have been proposed for the gravitational waves and multi-messenger astroparticle physics topic:

- Gravitational waves: Today, Virgo is the main instrument for gravitational wave physics in Europe. The next-generation experiment “Einstein Telescope” is currently being discussed widely.
- CTA: This array of Cherenkov telescopes will increase the sensitivity to gamma rays by a factor ten with respect to today’s experiments.
- Auger: The Pierre Auger observatory detects highest energy cosmic rays as air showers.
- High-energy neutrinos: High-energy neutrinos can be detected in large arrays such as IceCube or ANTARES. A future development is the KM3NeT array.
- NUSTAR-FAIR: This experiment will use radioactive beams at the FAIR facility to improve the understanding of the nuclear structure.
- HADES: The HADES experiment will study the properties of nucleons.