ECFA
European Committee for Future Accelerators

10th ECFA Newsletter

Participants at the first ECFA workshop on e+e- Higgs/EW/Top Factories at DESY in Hamburg

Following the 111th Plenary ECFA meeting
17 and 18 November 2022
https://indico.cern.ch/event/1212248/

Winter 2022

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Introduction

Since the last plenary ECFA meeting at the end of July, ECFA's activities have again been dominated by the implementation of the recommendations of the European Strategy update, with a major focus on the Detector R&D Roadmap and the e+e- Higgs factory study.

The implementation plan for the Detector R&D Roadmap, as presented at the July plenary meeting, was endorsed by the CERN Council at its meeting in September. Work is now progressing towards setting up the new Detector R&D (DRD) collaborations, with the goal to submit proposals by July 2023. Important meetings, open to the full community, will be held early in 2023. The purpose of these meetings is to kick off the preparation of the proposals in the technology areas. People interested in participating in these activities are encouraged to sign up at https://indico.cern.ch/event/957057/page/27294-implementation-of-the-ecfa-detector-rd-roadmap.

The first ECFA workshop, which took place in Hamburg from 5 to 7 October 2022, marked the first milestone in the e+e- Higgs factory study. The purpose of this activity is to bring together all of the e+e- Higgs factory efforts (ILC, CLIC, FCC-ee, CEPC) in order to share challenges and expertise, explore synergies and – wherever possible – develop together common tools and methods. The workshop was attended by about 200 participants in person and 145 online. It was encouraging to see experts from across different projects connecting and working together, in particular on simulation and reconstruction topics. However, it was also felt that stronger involvement from people working in other areas, such as the LHC, and also from the theory community, would be desirable. In order to stimulate new engagement and define concrete projects to get the work started, a set of focus topics is being proposed. It is essential for the field that there be a strong community and strong participation in these studies. Finally, we wish to express our thanks to the teams from DESY and the University of Hamburg for the excellent organisation of this workshop.

In this ECFA Newsletter you will find reports on the talks presented during the Plenary ECFA meeting held at CERN on 17–18 November. The open session on the Friday was devoted to presentations on the status of the implementation of the European Strategy update, covering the FCC Feasibility Study, the implementation of the Accelerator and Detector R&D Roadmaps and the ECFA e+e- activities. We also had a presentation on the newly established EURO-LABS project, which aims to provide transnational access to leading research infrastructures across Europe. In addition, the physics and upgrade plans of the LHCb and ALICE collaborations for running in the post-LS4 phase at the HL-LHC were presented. In addition, we heard a talk on the WLCG computing activities, including plans for the future. A topical session that took place during the afternoon was devoted to a discussion of the status of and plans and prospects for the various accelerator R&D activities. In that context, high-field magnet development, plasma and laser acceleration, the muon collider and energy-recovery linacs were discussed.

This Newsletter also contains short reports on ongoing LHeC and FCCeh activities. On this occasion, it is our great pleasure to thank Professor Max Klein from the University of Liverpool for his more than decade-long leadership in this area, which has now been handed over to Jorgen D'Hondt. In addition, the letter contains an update on the Physics Beyond Colliders activities at CERN, as well as a short report on the status of the Electron–Ion Collider (EIC) activities, with a focus on the European participation. It closes with news from major European laboratories.

Finally, we would like to take this opportunity to wish all of you a relaxing time over the upcoming holiday season and all the best for 2023.

Karl Jakobs
ECFA Chair

Patricia Conde Muíño
ECFA Scientific Secretary

Implementation of the European Strategy for Particle Physics

FCC Feasibility Study

by M. Benedikt (CERN) and F. Zimmermann (CERN)

As reported previously (ECFA Newsletters #7, #8 and #9), the Future Circular Collider (FCC) Feasibility Study (FS) was launched by the CERN Council (see CERN/3566 and CERN/3588) in response to the 2020 update of the European Strategy for Particle Physics. The FCC FS is expected to deliver a Feasibility Study Report by the end of 2025. A mid-term review is scheduled for autumn 2023. The entire FCC governance structure (membership of the Steering Committee, Collaboration Board, Scientific Advisory Committee and Coordination Group) was established by summer 2022.

Presently, the main activities, supported by the EC H2020 Design Study FCCIS, the Swiss CHART programme and individual institutional collaborators, are focused on: (1) bringing the detailed accelerator design to the next level; and (2) starting local activities, which include talks with all the municipalities located along the collider's path in France and Switzerland.

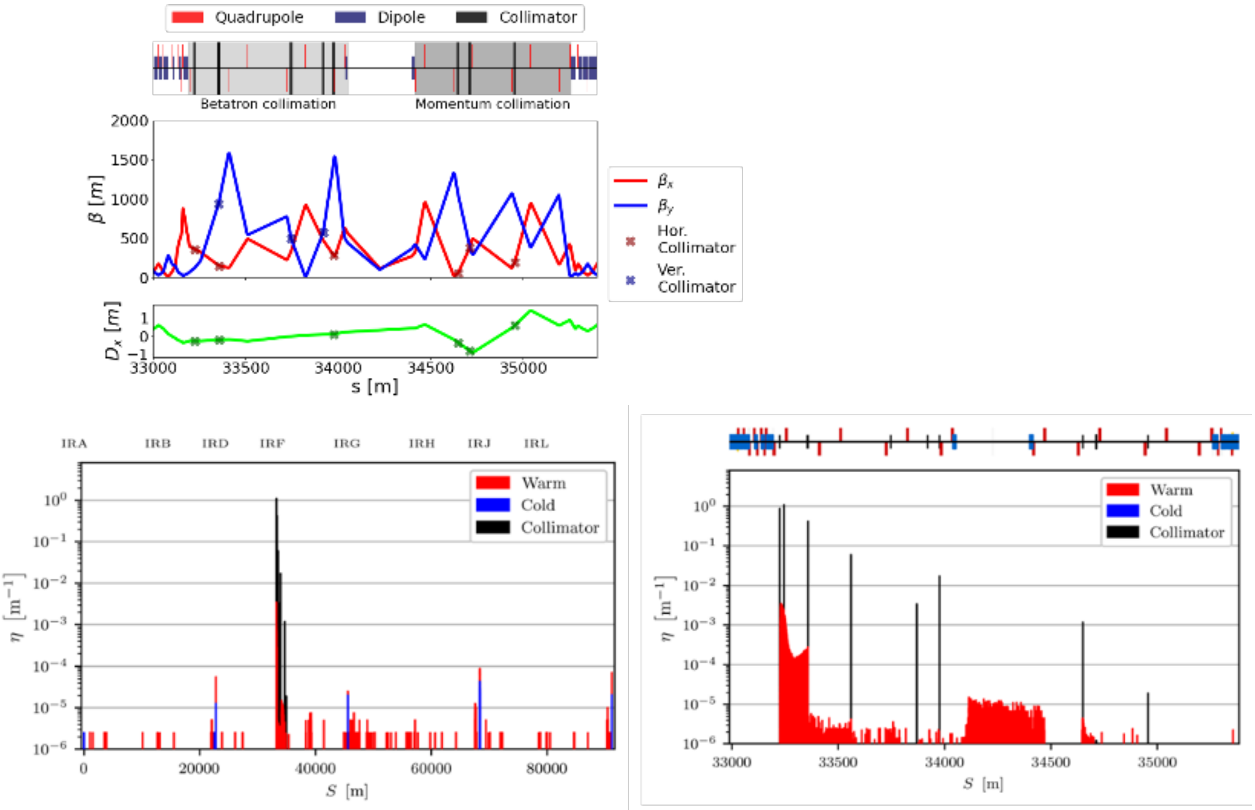

Figure 1: New collimation optics for 4 interaction points (left, Michael Hofer) together with simulated global (centre) and local loss maps (right, Andrey Abramov).

The FCC-ee optics was further refined. Optimisation of the beam combination and separation schemes for Higgs and top quark running increased the space available for radiofrequency cryomodules in the long technical sections. In the experimental insertions, an optics location for Compton polarimeters was developed. New collimation optics was designed for the case of four interaction points. First tracking studies for this optics indicate an excellent cleaning performance (see fig. 1).

In early October 2022, two topical reviews were organised, both chaired by Professor Andrew Parker of Cambridge University, who also serves as the Chair of the new FCC Scientific Advisory Committee. The first was a review of the “Superconducting Radiofrequency (SRF) Systems Layout with Associated Civil Engineering (CE) and Technical Infrastructure (TI) Concepts”. Here, the reviewers provided constructive feedback on general progress with RF concepts, underlined the importance of energy efficiency, lent full support to the high-Q SRF R&D programme on bulk Nb and Nb/Cu cavities, suggested adopting a higher Q_0 value for the 800 MHz bulk Nb cavities, supported the separation of collider and booster RF in different locations, and recommended continuing high-efficiency RF power source R&D with industrial partners to reduce overall power consumption. The second review, of the “CE and TI requirements for FCC experimental sites”, endorsed the baseline concept for the FCC experiment site underground structures, namely an experimental cavern with a single experimental shaft for the main detector, linked via a transfer tunnel to the service cavern, with a second shaft (similar to the present CMS layout), and suggested carrying out a detailed study of the implications of the stray field from unshielded FCC-hh detector magnets and considering alternatives with shielded magnet systems.

A collaboration between PSI, CEA, CNRS, INFN and CERN is working towards finalising the design of the FCC-ee injector complex. This includes the optimisation of the linac operating parameters (number of bunches per pulse, bunch spacing, repetition rate), damping ring size, energy and damping time, the possible use of the damping ring also for electrons, a proposed reduction of the target normalised emittances at booster injection from earlier $ge_{x,y}$=50x50 mm to 10x1 mm, the choice of booster injection energy, and last not least the location of the pre-injector complex, possibly on the CERN Prévessin site, with a transfer line towards the FCC, starting from the existing SPS tunnel.

Two mock-ups of critical accelerator components are being planned. An arc half-cell mock-up should be constructed at CERN. The arc half-cell is the most recurrent assembly of mechanical hardware in the accelerator (about 1500 similar FODO cells). The mock-up will lead to functional prototype(s), followed by a pre-series and, finally, series production. Building the mock-up makes it possible to optimise and test manufacture, integration, installation, assembly, transport and maintenance by working, where required, with structures of equivalent volumes, weights and stiffness.

A mock-up of the FCC-ee interaction region is proposed at INFN Frascati. Starting from the central interaction point vacuum chamber made from AlBeMet162, held by a strong outer support tube, a steel transition plus bellows, the mock-up could later be extended to include the trapezoidal vacuum chamber with remote vacuum connection, a placeholder luminosity monitor, a compensation solenoid, the first superconducting quadrupole with cryostat, more beam pipes, support structures for quadrupole and cryostat, and vibration and alignment sensors.

The Electron Storage Ring of the Electron–Ion Collider (EIC) in the US is similar to, but more challenging than, the FCC-ee. The beam parameters are almost identical to FCC-ee Z operation, but the EIC aspires to reach twice the maximum electron beam current, or half the bunch spacing, at a lower beam energy. More than ten areas of common interest have been identified by the FCC and EIC design teams. They will be addressed through joint EIC–FCC working groups, which are still evolving. The EIC will start beam operation about a decade prior to FCC-ee, providing an invaluable opportunity to train the next generation of accelerator physicists on an operating collider and to test hardware prototypes, beam control schemes, etc.

Concerning progress with regional activities, elected representatives from the French departments of Haute-Savoie and Ain and from the Swiss canton of Geneva visited CERN.

Information meetings and exchanges were organised with the Presidents and *Préfets* of Ain and Haute-Savoie in preparation for the next steps. All communities concerned by the FCC path were approached directly via information letters co-signed by the *Préfet* of the Auvergne-Rhône-Apes region and by the CERN Director-General (for France), or by the *Conseiller d'État de Genève* and the CERN Director-General (for Switzerland). Consultations with individual communities are ongoing. First contact with all 42 communes is planned to be completed before the end of year. Technical discussions on territorial implementation, water use, excavation material reuse, etc., have started with Haute-Savoie.

In conclusion, the FCC FS is moving forward as planned towards the next major milestone, which is the mid-term review that will take place in autumn 2023.

Implementation of the Accelerator R&D Roadmap

by D. Newbold (STFC Rutherford Appleton Laboratory)

Following the publication of the Accelerator R&D Roadmap in early 2022[1], the remainder of the year has been spent in developing a structure and plan for implementation of the R&D objectives in the period before the next update of the European Strategy for Particle Physics. The R&D work is intended both to progress the state-of-the-art in accelerator technology, and to provide concrete information to the strategy process on the timelines and cost for future particle physics facilities. Much of the proposed R&D is aimed at improving the performance of future accelerators (and hence the accessibility of new discoveries) without commensurate increases in construction or operations cost. The full significance of constraints due to energy costs has become increasingly apparent during 2022, making this work more necessary and urgent than ever.

The practical coordination of R&D work within the five topics identified in the European Strategy will be carried out by Coordination Panels, which will bring together technical experts with representatives of the main stakeholders in each topic. The panels will work closely with the R&D community, laboratories and institutes, and funding agencies to define in detail and then carry out an affordable R&D programme towards the objectives defined in the Roadmap. The leadership of the panels is now fully in place:

- High-field magnets: M. Lamont (CERN); P. Vedrine (IRFU)
- RF structures: G. Bisoffi (INFN Padova); P. Mcintosh (DL)
- Plasma acceleration: W. Leemans (DESY); R. Patahill (RAL)
- Muons: S. Stapnes (CERN); D. Schulte (CERN)
- Energy-recovery linacs: J. D'Hondt (VUB); M. Klein (U. Liverpool)

The panels have been working intensively to set up the necessary collaborative structures, which in some cases includes the definition of a formal collaboration governed by MoU / MoC agreements between partners. Each panel strongly welcomes interest from new collaborators and institutes, both now and in the future – direct contact with the panel chairs is invited.

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[1] https://arxiv.org/abs/2201.07895

The first formal review of R&D progress was held by LDG in November 2022. The broad conclusion was that substantial achievements in organisation and planning have been made across all five areas, but that careful balancing of resources and investment will be needed to make sure that a broad front of R&D can be maintained, offering the widest spectrum of possibilities for new facilities for the medium and far future of the field. In some cases, new sources of funding must be found, and actions to address this at European level are underway. The conclusions of the first review will be presented to CERN Council in early 2023, and the next review will take place in November 2023.

Towards Detector R&D collaborations – update on the Detector R&D Roadmap

by P. Allport (University of Birmingham)

The implementation plan for the ECFA Detector R&D Roadmap was presented to the CERN SPC and Council as CERN/SPC/1190-CERN/3679 and endorsed by both, as reported by the Director–General at the October 2022 Directorate meeting. The next stages in the process are therefore to encourage the formation of the new detector R&D collaborations (DRDs), to set up the review structure reported already in the last ECFA newsletter and to follow up on the other General Strategic Recommendations also listed in the Roadmap document. One important body is the ECFA Detector Panel (EDP). Its membership has been defined and endorsed by Plenary ECFA. It consists of: Phil Allport (Birmingham) and Didier Contardo (IP2I Lyon) as Co-Chairs; Doris Eckstein (DESY) as Scientific Secretary with specific expertise in solid state detectors; Silvia Dalla Torre (INFN Torino) as expert in gaseous detectors; Inés Gil Botella (CIEMAT Madrid) as expert in liquid detectors; Roger Forty (CERN) as expert in PID and photon detectors; Laurent Serin (IJCLab) as expert in calorimetry; Valerio Re (Bergamo) as expert in electronics; Karl Jakobs (Freiburg) ex-officio as ECFA Chair; Ian Shipsey (Oxford) as ex-officio ICFA Instrumentation Innovation and Development Panel (IIDP) Chair; plus APPEC- and NuPECC-appointed observers. A member with specific expertise in quantum and emerging technologies is still being sought but this area can also be covered for the time being by Ian Shipsey.

I would like to note my thanks to Arno Straessner and Lucie Linssen, who have decided not to continue on the EDP, for their support of the Panel over many years.

A new mandate for the EDP, reflecting the roles described in CERN/SPC/1190-CERN/3679, was prepared. It was presented at the November Restricted ECFA meeting and supported by the delegates. The main focus for the EDP will initially be the reviewing of DRD proposals in support of the new CERN Detector R&D Committee (DRDC) as described in the last newsletter and CERN/SPC/1190-CERN/3679. The EDP will also contribute expert members to the DRDC and assist with monitoring progress towards the goals outlined in the Detector R&D Roadmap. It will also be the body that plays a custodial role for the Roadmap, following the evolving landscape in terms of detector requirements for future facilities, and be responsible for developing any changes of emphasis or direction linked to the next update of the European Strategy for Particle Physics.

It was proposed in the revised mandate that a fixed term be implemented for all the positions within the EDP. The two Co-Chairs would have terms of three years (renewable once) with periods in office to run 18 months out of phase with each other to provide continuity. Similarly, the positions of Scientific Secretary and Member should have terms of three years, renewable once, giving a maximum period of six years, and it is intended that membership would also be staggered in time to ensure reasonable overlaps of experience when terms come to an end. Given that five members of the updated Panel started in the previous EDP, it is assumed that such staggering of membership should follow naturally once work gets under way.

Document CERN/SPC/1190-CERN/3679 also suggests the establishment of a new ECFA Training Panel, which will address the key General Strategic Recommendations in that area and the specific proposal from Roadmap Task Force 9, covering this topic.

The proposed timeline for community consultation, proposal preparation and review, as detailed in CERN/SPC/1190-CERN/3679, was also outlined again, with a reminder for everyone to encourage their communities to sign up at https://indico.cern.ch/event/957057/page/27294-implementation-of-the-ecfa-detector-rd-roadmap and for institutes to follow up on the discussions with their funding agencies, in the light of the Council's approval of the implementation process and the key messages emphasised at the April Plenary Resources Review Board meeting.

The EURO-LABS project

by P. Giacomelli (INFN Bologna)

The European Laboratories for Accelerator-Based Sciences (**EURO-LABS**) project aims to provide unified transnational access to leading research infrastructures across Europe. Taking over from previously running independent EU programmes (ENSAR2, AIDAinnova, I.FAST), EURO-LABS represents a pioneering step in bringing together, for the first time, at the European level, the nuclear physics and the high-energy physics (HEP) accelerator and detector communities. EURO-LABS started on 1 September 2022 and will run for four years. This will result in cross-fertilisation of these disciplines by providing access to a wide range of accelerator facilities to do frontline science enhancing existing synergies and collaborations. The quest of the community is the pursuit of excellent science in the nuclear and HEP domains, including their important role in applications and technology.

The project has funding of about 15 MEUR, 14.2 of which come from the EU call HORIZON-INFRA-2021-SERV-01-07. The EURO-LABS consortium is composed of 33 partners, 25 beneficiaries and 8 associated partners, from EU and non-EU countries. The project forms a large network of laboratories and institutes ranging from modest-sized test infrastructures to large-scale ESFRI facilities such as SPIRAL2. In total, 43 research infrastructures, from 12 countries in Europe, are covered by the EURO-LABS project, as can be seen in figure 2. With this large network of research infrastructures, many different types of beams can be offered, with a variety of particle types, ranging from electrons, protons, neutrons and mesons to ions (both stable and radioactive) in a wide range of energy. Also, several irradiation facilities are offered within EURO-LABS for many possible experimental activities.

The kick-off meeting of the project was held in Bologna, Italy, from October 3rd to October 5th, 2022. It saw the participation of more than 70 people, with representatives from every laboratory involved in the project. At the meeting the structure of EURO-LABS and its activities were discussed in detail, and the procedures to select proposals and grant transnational access to research groups were agreed upon. The Governing Board met for the first time, elected its chairperson and endorsed the management team and the steering committee of the project. EURO-LABS is coordinated by INFN and structured into 5 Work Packages (WPs), as visible in Figure 2. WP1 provides the management of the project. WP2, WP3 and WP4 control the TA and research improvement activities of nuclear physics, high-energy accelerator and high-energy detectors, respectively. WP5 is a transversal work package that will provide dissemination, open data, machine learning tools and training to all the participants of the project.

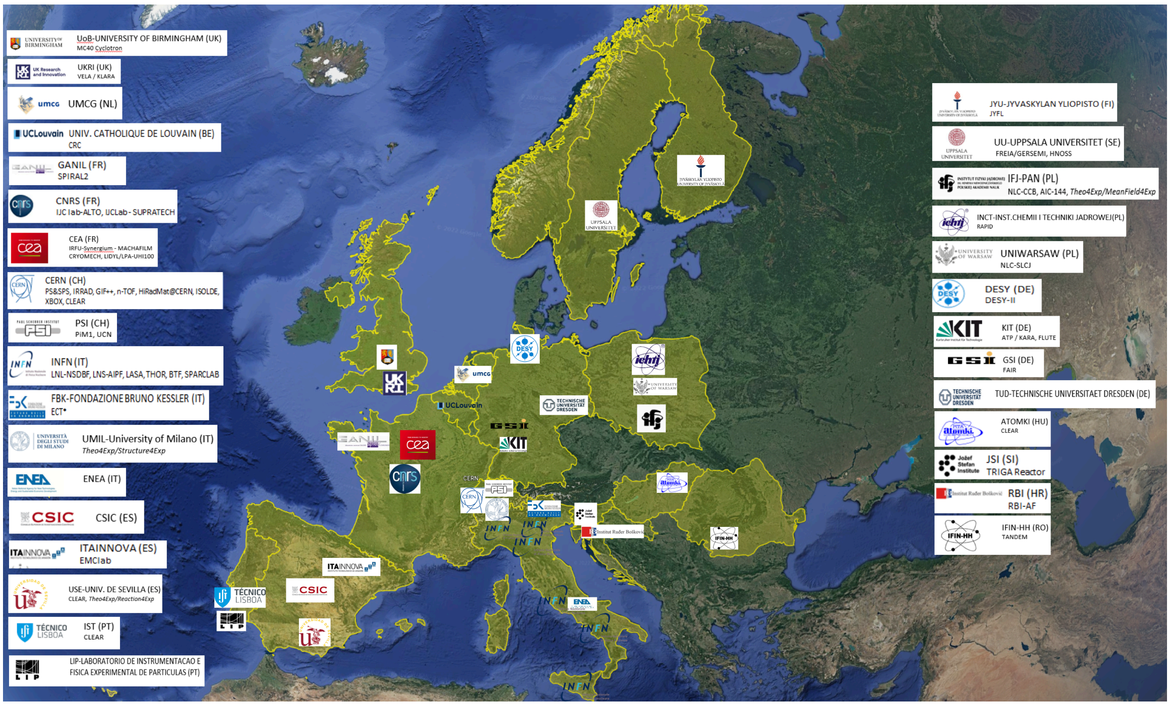


Figure 2: Map of the Research Infrastructures covered by the EURO-LABS project and the countries in which they are located.

Reports on ECFA studies towards an e^+e^- factory

by A. Robson (University of Glasgow)

The ECFA study towards an e^+e^- Higgs/Electroweak/Top factory is intended to bring together communities and activities across the proposed projects, to explore synergies and discuss challenges. So far the study has held a rich programme of seminars, topical meetings and mini-workshops, and a milestone was recently reached with the first workshop, held at DESY from 5 to 7 October. Some 200 participants in person, and 145 online, contributed to lively plenary and parallel sessions and it was positive to see experts from across different projects connecting. Aspects of simulation and reconstruction are being actively worked on together; and more widely, thematic topics are emerging as good places for people to contribute. It is essential for the field that there be a strong community and strong participation in e^+e^- studies and, by working across projects, it is hoped that the ECFA study can provide an entry point for national groups.

In order to stimulate new engagement and trigger some concrete studies, the study proposes to define a set of focus topics, first discussed at the Hamburg Workshop. These topics do not aim to map the physics programme of a future Higgs factory comprehensively, but rather to highlight places where work could usefully add to the overall picture, and to give guidance to people who would like to contribute to the ECFA study. Topics span a range of physics areas and include many potential aspects, from theory calculations and Monte Carlo generator development; through detector-level studies including reconstruction techniques and calibration methods, and detector requirements; to

EFT interpretations. The initiative is intended to build on existing analysis tools, examples and samples that can be shared among the projects and developed cooperatively. Details are being refined and further information will follow.

Looking ahead, the study plans to continue the ongoing series of topical meetings and mini-workshops, with two further overall workshops in 2023 and 2024, converging on a final ECFA report in 2025 that will be input to the next European Strategy update, which is provisionally expected in 2026–27. The whole community is strongly encouraged to consider how they can individually contribute to the study, towards the future success of the field. In particular, group leaders and principal investigators are very strongly encouraged to enable the involvement of early-career researchers under their mentorship, including postdoctoral researchers and PhD students.

LHCb upgrade II: physics and upgrade plans

by C. Parkes (University of Manchester, CERN)

The original LHCb experiment operated in LHC Runs 1 and 2 and finished data taking at the end of 2018. It has produced nearly 650 scientific papers, including major results in rare beauty and charm decays, the observation of CP violation in three new systems, and the discovery of 60 hadronic particles. The LHCb upgrade I detector was installed during the second long shutdown (LS2) and will operate during LHC Runs 3 and 4. This major project was achieved on budget, and commissioning is proceeding well. The collaboration has doubled in size since the start of LHC operations.

The LHCb upgrade II will build on these successes to fully exploit the capabilities of the HL-LHC era in flavour physics and beyond. The experiment will test the CKM paradigm with unprecedented accuracy, have sensitivity for the CP violating phase ϕ_s below the SM prediction in multiple channels, and be the only facility with the realistic potential of observing CP violation in charm mixing. In addition to its world-leading capabilities in flavour physics, the LHCb programme is increasingly broad, encompassing research topics such as heavy ions, fixed-target, electroweak, QCD and dark sector searches.

The upgrade II project was proposed in a letter of intent [1] in 2017, followed by a physics case [2] in 2018, and the framework technical design report [3] was approved by the LHC Committee (LHCC) earlier this year. Ongoing R&D will lead to subdetector TDRs. Funding agency discussions are under way, with many relevant R&D grants awarded and full construction funding awarded by one of the major funding agencies. The detector will be installed in LS4 (2033–2034) and operate in Runs 5 and 6. Some consolidation and preparatory work is planned for LS3.

The upgrade II detector will have a similar footprint to the previous detector versions but introduce innovative technologies for the detector and data processing to cope with operations at 25 times higher instantaneous luminosity than in Runs 1 and 2 and collect more than 300 fb^{-1} of data.

A number of systems will utilise precision timing information. A fully 4D vertex detector (VELO) is planned; adding 50 ps resolution to pixels with 50×50 μm^2 size could achieve a performance similar to that of the previous detectors in the harsh pile-up conditions. Test-beam results have demonstrated 15 ps resolution sensors after heavy irradiation, and 28 nm ASIC designs are under way. A “5D” calorimeter is planned, with spatial, energy and timing performance. Different technologies are discussed for different regions, with the inner region requiring 1 MGy radiation tolerance and SPACAL designs using crystal fibres in 3D-printed tungsten absorbers tested. Test-beam results show 15 ps time and $10\%/\sqrt{\mathrm{E\ (GeV)}}$ energy resolution. Pion, kaon and proton particle identification over a wide momentum range is central to LHCb's physics programme. Two RICH systems and a time-of-flight system known as TORCH will rely on precision timing.

The tracking system will utilise the emerging radiation-tolerant monolithic active pixel sensor (MAPS) technologies at scale in the systems both before and after the dipole magnet. A ¼ scale HV-CMOS prototype has been submitted for manufacture. In the tracking stations after the magnet, the main area will be covered with scintillating fibres (SciFi), with the MAPS in the inner region. The SciFi technology has been demonstrated in upgrade I but micro-lenses and cryogenic cooling R&D is under way for the SiPMs to read these out. Equipping the inner sides of the dipole magnet with scintillating bars would extend the detector acceptance to lower momentum particles. Novel micro-pattern gas detectors (μRWELL) are planned for the inner regions of the muon system, with additional shielding to be installed.

The upgrade I system uses 40 MHz readout into common FPGA cards and a novel fully software trigger with the first level performed in GPUs. A similar concept is planned for upgrade II, but at 200 Tb/s this will be the highest bandwidth particle physics trigger system. Further exploitation of hybrid architectures is planned.

In summary, LHCb upgrade II is a large-scale project, larger than the previous LHCb detector generations and with a wider physics programme, for installation in the 2030s and operation through to the 2040s. It is now in its R&D stage, with use of a number of innovative technologies being studied, which could act as a pathfinder for future accelerator projects. The collaboration continues to grow and encourages new collaborators to assist in realising our ambitious plans.

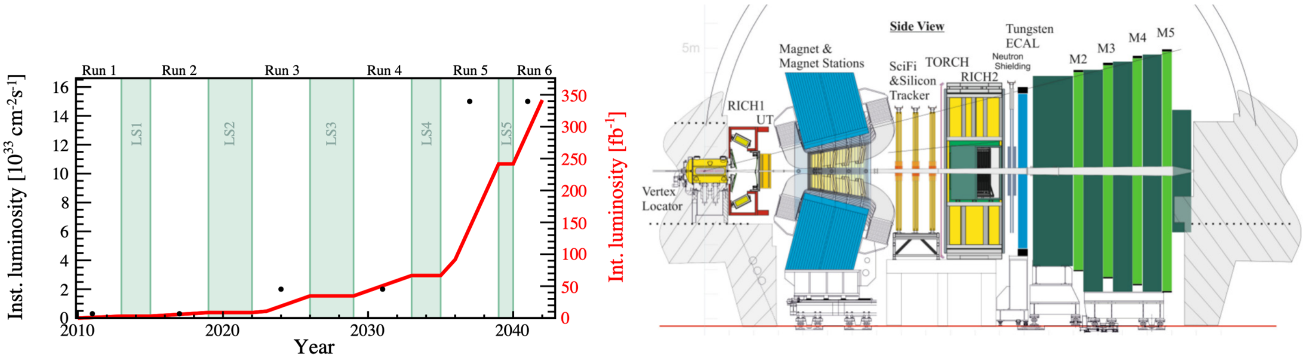


Figure 3: (left) Instantaneous and integrated luminosity expected for the full LHCb programme; (right) the layout and subdetector systems of the upgrade II design.

References

[1] Expression of Interest for a Phase-II LHCb Upgrade, LHCb collaboration, CERN-LHCC-2017-003

[2] Physics Case for an LHCb Upgrade II, LHCb collaboration, CERN-LHCC-2018-027

[3] Framework TDR for the LHCb Upgrade II, CERN-LHCC-2021-012

ALICE 3: physics and upgrade plans

by L. Musa (CERN) for the ALICE collaboration

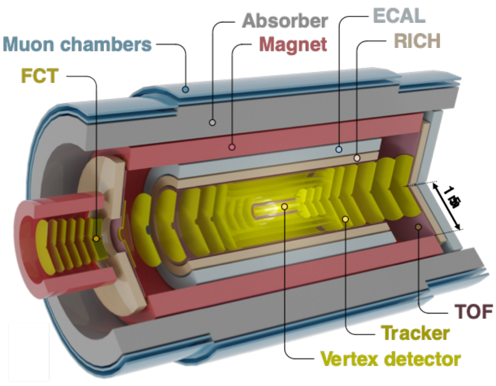
The ALICE experiment aims to study the properties of the high-temperature phase of QCD and how they arise from the strong interaction between partons. These goals are pursued via a comprehensive study of ultra-relativistic nuclear collisions at the LHC, which provide unique experimental access to the hottest and longest-lived quark–gluon plasma (QGP), a deconfined state of quarks and gluons. The Runs 1 and 2 campaigns at the LHC have led to crucial advances in our understanding of the macroscopic and microscopic properties of the QGP and, more generally, of an ensemble of QCD phenomena. For a review of the main findings of the ALICE experiment in Runs 1 and 2, see [1]. The upgrades that have been installed in Long Shutdown 2 (2019–2021) in the LHC and ALICE will make it possible to collect Pb–Pb collisions at a higher interaction rate of 50 kHz, more than 50 times the rates achieved for minimum bias data taking in Runs 1 and 2. In addition, an entirely new inner tracking system significantly improves the pointing resolution and tracking efficiency, especially for particles with low momentum. Thanks to these upgrades, significant progress is expected in the Runs 3 and 4 campaign, notably in the areas of heavy-flavour and dilepton studies (see [2] for a review).

However, crucial questions will remain unanswered at the end of Run 4. Achieving a textbook understanding of the rich phenomenology of QCD matter, connecting parton energy loss, collective flow, hadronisation and electromagnetic radiation in a unified description, will require a novel experimental approach. To this end, the ALICE collaboration has presented a letter of intent (see [3]) for a novel detector designed to fully exploit the potential offered by the LHC for the study of high-energy nuclear collisions in Runs 5 and 6. The new detector is named ALICE 3, which refers to the third phase of the ALICE experiment. Below we provide a few examples of its key physics objectives and drivers.

One important area is the study of heavy-flavour propagation. In order to discriminate between the different regimes of in-medium energy loss and reveal the onset of charm isotropisation, more differential measurements than those accessible with the current experiments are needed, e.g. of correlations between fully reconstructed charm hadron pairs over a wide rapidity range. In addition, in order to establish a firm connection between parton transport, collective flow and hadronisation, the study of parton energy loss needs to be extended down to the momenta typical of diffusion phenomena. To this end, precision measurements of the spectra and flow coefficients at very low momentum are indispensable, not only for charm, but also for beauty hadrons. Another key goal is the study of the formation of hadrons from the deconfined QGP. In this regard, the measurement of the production of multi-heavy-flavour hadrons, P-wave quarkonia and exotic states will offer unprecedented sensitivity. In this area, measurements of momentum correlations of D and D* mesons provide unique sensitivity to hadron interaction potentials to elucidate the nature of exotic states. Access to the full time evolution of the QGP temperature calls for a comprehensive study of the azimuthal asymmetry of the production of dileptons as a function of their transverse momentum and their mass to provide a direct connection to the emission time. The deconfinement phase transition is expected to be accompanied by a partial restoration of chiral symmetry, leading to a modification of the dilepton spectrum in the light vector meson mass range. Unambiguous experimental detection of this effect would be of paramount importance. Event-by-event fluctuations of conserved charges (including strangeness and charm) are directly connected to the equation of state. These measurements will constrain the susceptibilities of the quark–gluon plasma and test the realisation of a cross-over phase transition as predicted by lattice QCD.

The detector for this physics programme also offers excellent opportunities for a programme in high-statistics hadronic physics, including measurements of hypernuclei, the search for as-yet undiscovered supernuclei, in which a nucleon is replaced by a charmed baryon, and the measurement of the production of antinuclei in the decay of beauty baryons, which has important implications for dark matter searches. Moreover, ALICE 3 will open up new channels in ultra-peripheral collisions, including a search for axion-like particles in two-photon events in a significantly extended parameter space. A special detector arrangement to reconstruct photon conversions at ultra-low transverse momenta will make it possible to test the infrared limit of QED as a gauge theory.

These objectives call for a new detector, schematically depicted in the figure below, featuring a high-speed, very high-resolution and ultra-lightweight silicon tracker, positioned very close to the interaction point. Its first layers are inside the LHC beam pipe at a radial distance of about 5 mm from the interaction point, which poses R&D challenges on several fronts. The mechanical design requires the development of a retractable ultra-lightweight structure as support for the sensors, while maintaining a vacuum separated from the primary LHC volume and ensuring sufficient cooling to take out the heat dissipation from the beam and the sensors. For the sensors, a 65 nm CMOS process is considered as a baseline. First tests have already shown excellent performance of the pixels, and first results on stitched wafer-scale sensors are expected in 2023.



ALICE 3 detector layout

Particle identification is provided by a silicon time-of-flight system with a time resolution of 20 ps and a ring-imaging Cherenkov detector with an aerogel radiator and a high-resolution readout plane with silicon photon sensors. For the time-of-flight, the main R&D line aims to integrate a gain layer in monolithic CMOS sensors to achieve a time resolution better than 20 ps. A first demonstrator chip is currently being manufactured and first tests are expected to start in early 2023. In parallel, thin low-gain avalanche diodes (LGADs) with external circuitry are being studied and optimised. For the RICH detector, the R&D goal is to integrate the digital readout circuitry in SiPMs to achieve efficient detection of photons in the visible range. Photons are detected by an electromagnetic calorimeter, and muon identification is provided by the muon identifier, which consists of an absorber followed by two planes of readout chambers. In the forward direction, the forward tracker consists of low-material tracking planes in a dipole field, to detect photons at low momentum by their conversion. The physics capabilities of the proposed apparatus for the scientific programme outlined above have been demonstrated for a set of benchmark physics channels, as reported in the ALICE 3 letter of intent [3]. These activities on different silicon sensors cover strategic areas since such sensors are of interest far beyond this specific detector. This will also allow us to take advantage of synergies with projects at other facilities.

While the remaining detector systems can be based on technologies that are more established on a conceptual level, they also provide interesting R&D opportunities. The electromagnetic calorimeter will require the optimisation of the absorber-scintillator stacks, in particular in view of the machineability and produceability to instrument large surfaces. For the muon identifier, solutions based on scintillators and RPCs are being explored. The former requires the design of scintillating bars with integrated wavelength-shifting fibres and SiPM readout. The latter requires an R&D programme to develop RPCs that can be operated with eco-friendly gases. The letter of intent for ALICE 3 has received a very positive review by a dedicated expert panel appointed by the LHCC. The committee emphasised that ALICE 3 provides a roadmap for exciting heavy-ion physics, with LHC Runs 5 and 6 set to fully exploit the physics potential of the LHC. It was recommended that the collaboration proceed with the necessary R&D and design activities as well as with the preparation of an organisational and funding scheme. Technical design reports are expected to be presented to the

LHCC for review in 2026 and 2027. An intermediate review of the project planning and resources by the Upgrade Cost Group is scheduled to take place in late 2023 or early 2024.

References

[1] ALICE collaboration, “The ALICE experiment – A journey through QCD”, *arXiv:2211.04384*

[2] Z. Citron *et al.*, “Report from the Working Group 5: Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams”, *arXiv:1812.06772*

[3] ALICE collaboration, “Letter of Intent for ALICE 3: A next-generation heavy-ion experiment at the LHC”, *arXiv:2211.02491*

New general-purpose experiments with ep/eA collisions at the LHC and/or FCC

by O. Brüning (CERN), J. D'Hondt (Vrije Universiteit Brussel) and M. Klein (University of Liverpool)

Following the publication of the updated CDR [1], CERN continues to support studies for the LHeC and the FCC-eh as potential options for the future and to provide input to the next update of the European Strategy for Particle Physics. The CERN Directorate appointed Jorgen D’Hondt (Brussels) as spokesperson of the efforts to further the development of the scientific potential and possible technical realisation of an ep/eA collider and the associated detectors at CERN, with emphasis on the FCC.

Similar to the inclusive FCC-ee/eh/hh programme, the ep/eA LHeC programme has the potential to empower the (HL-)LHC physics programme of ATLAS and CMS in a unique way and allow a deeper exploration of the EW/Higgs/top/strong physics sectors of the Standard Model beyond what can be achieved with the proton–proton collisions at the (HL-)LHC. In many cases, adding the LHeC data to the HL-LHC data would result in significant improvements in precision Higgs physics similar to those expected when moving from the LHC to the HL-LHC.

At a recent workshop at IJCLab [2], the sense of innovation in the ep/eA community was illustrated. When the ep/eA community moves from HERA and EIC to higher energies at the LHeC and FCC-eh, the threshold is reached to open the window for EW/Higgs/top physics in deep inelastic scattering (DIS) processes for the first time. In addition, these programmes are unique in exploring the low Bjorken-x frontier by orders of magnitude beyond current DIS knowledge. At this stage, it is unclear what physics would be unlocked by breaking the proton and hadronic matter into even smaller pieces. Accordingly, an experiment at this high-energy ep/eA collider is truly a general-purpose experiment going beyond several frontiers of knowledge.

The advantage of a joint ep/pp/eA/AA/pA interaction experiment should be underlined. For example, reaching a precision of 2 MeV on the W-boson mass could be within reach. With the LHC and/or FCC proton and ion beams, at this stage independent of implementation strategies, the scientific added value of this opportunity needs to be further explored and documented.

To achieve the greatest impact in addressing some of our most profound questions in particle and nuclear physics, thematic working groups will soon be organised to innovate our scientific and technological research on ep/eA collisions.

Subscribe to the LHec/FCC-eh list via https://e-groups.cern.ch/ (use the search option, and search for “lhec-fcceh-all” in all e-groups).

[1] LHeC updated CDR: https://inspirehep.net/literature/1809802

[2] October 2022 workshop at IJCLab: https://indico.ijclab.in2p3.fr/event/8623/

Physics Beyond Colliders

by G. Arduini (CERN), J. Jaeckel (Heidelberg University) and C. Vallée (CPPM, Marseille)

This report updates the comprehensive overview of "Physics Beyond Colliders" (PBC) activities presented at the Plenary ECFA meeting in July 2022 with the most recent news from the PBC annual workshop held at CERN from 7 to 9 November 2022 [1], focusing on matters of short-term scrutiny.

The post-LS3 future of the unique ECN3 underground hall of the SPS North Area (NA) is a topic of intense activity connected to the NA consolidation programme for the coming years. The decision concerning a physics-agnostic ECN3 high-intensity facility is expected in March 2023. A corresponding PBC accelerator report documenting the NA complex implications is being finalised. The three experiments under consideration have also submitted letters of intent (LoI): HIKE provides a comprehensive description of the high-precision kaon physics programme proposed for the next two decades; SHADOWS presents its overall layout to search for new feebly interacting particles (FIPs) as well as an additional neutrino subdetector and updated background simulations; and SHiP, aiming for a high-sensitivity FIP search, has adapted its configuration to ECN3 and correspondingly updated its sensitivity curves. Assuming the high-intensity upgrade gets the green light, the experiments' LoI will have to be consolidated into proposals by autumn 2023 to provide more solid sensitivity estimates, detector designs and construction timelines as input to the choice of the experimental programme. The physics cases (precision kaon physics, feebly interacting particles and neutrino measurements) are being evaluated in the worldwide context by the PBC physics working groups. All findings, including accelerator and detector aspects, will be summarised in a PBC ECN3 document due by summer 2023.

Several other projects showed steady progress at the PBC annual workshop. The Forward Physics Facility proposed at the LHC has received strong support from the Snowmass community and was recommended for further study within PBC by the LHCC in September. LHC fixed-target physics has made a significant step forward, with the very promising start of operation of the SMOG2 gas storage cell at LHCb: feedback from the coming months of data taking will be instrumental in order to assess the ultimate physics potential of such devices in the longer term. Full definition of a fixed-target double-crystal setup is also now available for implementation of a proof-of-principle experiment during Run 3 at the unused LHC Interaction Region 3. Preparations for the future NA ion programme are well on track, with the setting up of an accelerator working group addressing ion sources and operational issues in the global CERN complex context, including future LHC needs. NA60++ is close to submitting a LoI to the SPS and PS Experiments Committee, and NA61 will better shape its post-LS3 ion programme in a workshop scheduled for December.

Reference:

[1] PBC annual workshop (7–9 November 2022 at CERN) https://indico.cern.ch/event/1137276/

Accelerator Roadmap R&D activities – status, plans and prospects

High-field magnets

by A. Siemko (CERN)

The CERN-hosted accelerator high-field magnet (HFM) programme is a technology-focused R&D mission aimed at developing the next generation of accelerator magnets for future colliders. The programme covers three main broad goals derived from the recommendations of the Accelerator R&D Roadmap, which includes a dedicated roadmap for accelerator high-field magnets. The first two objectives concern the development of accelerator magnets based on low-temperature superconductors (LTS) – essentially Nb_3Sn technology. The third objective of the HFM R&D programme is to investigate the suitability of high-temperature superconductor (HTS) technology use in accelerator magnets, where to date only a few early attempts have been made worldwide.

OBJECTIVE 1:

Design and demonstrate a full-size Nb_3Sn accelerator magnet to demonstrate the maturity of the most advanced technologies today, based on the HL-LHC design, i.e. 12 T magnets, and applying all the lessons learned from the US LHC Accelerator Research programme (LARP), the US High-Luminosity LHC Accelerator Upgrade project (AUP) and the HL-LHC project. In particular, the robust design and improved manufacturing capabilities using industrial production processes should be introduced in collaboration with industrial partners to adapt to the future production scale and optimise costs. The full-size demonstrator also aims to investigate at an early R&D stage the physical and technological effects associated with magnet length.

OBJECTIVE 2:

Explore the limitations of the LTS state-of-the-art technology and push Nb_3Sn magnet technology to its practical limits in terms of ultimate performance, towards the 16 T target targeted by the FCC-hh.

OBJECTIVE 3:

Explore the capabilities and limitations of state-of-the-art HTS and magnet technology based on these superconductors. Demonstrate the suitability of HTS superconductors for accelerator magnet applications by providing evidence of the use of HTS technology beyond the Nb_3Sn range, with a target in excess of 20 T.

Efforts made in recent years in Europe and the US in the development and construction of magnets based on the latest Nb_3Sn technology have not overcome the 14 T barrier for magnets with a useful aperture for accelerators. This is mainly due to the limitations imposed by the state-of-the-art superconductor Nb_3Sn. While the latest results obtained in the HFM programme by the group from the University of Geneva and similar results obtained in the US show that the requirements for 16 T magnets for the FCC-hh regarding the current density in the superconductor have been achieved (see fig. 4), the conductor stress/strain sensitivity and thermomechanical behaviour and degradation of magnet performance are the main causes limiting the crossing of the 14 T barrier. The HFM programme's strategy is to overcome this limitation in at least one of the two defined development pathways:

- Development of new Nb_3Sn wire structures with 50 to 100% increased mechanical strength.

- Development of novel magnet coil structures with a stress management approach to deal with performance limitations due to Nb_3Sn stress/strain sensitivity and thermomechanical behaviour.

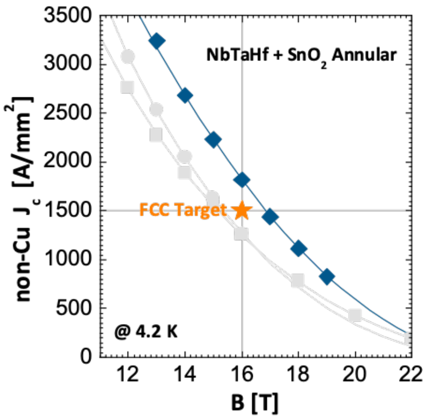


Figure 4. Critical current density in prototype Nb_3Sn multifilamentary wires with internal oxidation process (courtesy of C. Senatore).

The second task of the HFM programme is to assess the feasibility of accelerator magnets based on HTS materials, among which the ReBCO and Bi-2212 superconductors are the most promising candidates. R&D efforts on these technologies are at an early stage of development. Nevertheless, numerous possible limitations associated with the current state-of-the-art ReBCO and Bi-2212 superconductors have been encountered and will need to be addressed. These concern the following issues in particular:

- ReBCO conductor shear stress sensitivity and degradation
- large magnetisation of ReBCO conductors
- limited ability of ReBCO and reacted Bi-2212 cables to bend at small radii, forcing specific structures of magnet coil ends
- quench protection of accelerator-size magnets made with ReBCO and Bi-2212 HTS coils with high current and high stored energy densities.

These issues will be addressed primarily by focusing on the HTS superconductors themselves by:

- improving the ReBCO superconductor for low demand of magnetisation in accelerator magnets
- developing practical HTS cables
- developing alternative HTS superconductors such as IBS.

In parallel with the work on superconductors, groundwork on the development of HTS magnet technology will be carried out, in particular:

- development of subscale HTS insert magnets designed to work in the background field, and development of hybrid high-field magnets
- development of the first standalone HTS demonstrator magnets.

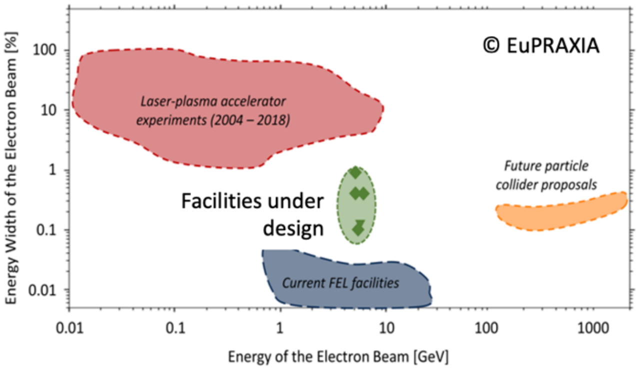
The LTS and HTS magnet technology challenges faced by the HFM R&D programme are numerous and significant, requiring decisive advancement beyond the state-of-the-art to make the next-generation magnets possible. This will require a high degree of innovation and exploration of emerging technologies, such as those required for the HTS accelerator magnets.

Fostering and taking advantage of collaborations with EU national laboratories is an essential part of the HFM programme, as is linking to ongoing worldwide efforts, particularly in the US and Japan. The HFM programme is at present in the final stage of implementation. The main targets have been defined and the challenges to meeting them have been shared with EU national laboratories. The intention is to accelerate the R&D within the HFM programme, focusing on milestones to be achieved before the next European Strategy update.

High-gradient plasma and laser acceleration

by R. Pattathil (RAL)

This presentation reported on the progress on the Plasma Accelerator pillar of the European Particle Physics Roadmap implementation activities. The current status of the laser- and beam-driven plasma accelerator programmes worldwide was presented, along with the currently published results on energy, energy spread and emittance of electron beams obtained through laser-driven and beam-driven (both electron- and proton- driven) wakefield acceleration. Although the beam parameters obtained from plasma accelerators today are not yet in the ballpark of those required for future colliders as illustrated in the figure, there are potential ways to get there, and the activities described in the European Particle Physics Roadmap illustrates the strategy. The talk outlined the main activities required in this regard, which three main elements:



- A feasibility and pre-CDR study for high gradient plasma and laser accelerators and their particle physics reach, consisting of
    - Evaluating the state of the art in detail and providing an assessment on its suitability
    - Determining theoretical limits, extrapolating experimentally achieved parameters for collider-relevant aspects
    - End-to-end simulations, with scalable parameters relevant for High Energy Physics (HEP)
    - Physics case for plasma-accelerator-based HEP and preliminary particle physics experiments
- Demonstration of laser-driven plasma accelerator at kHz or above
- Demonstration of electron and proton-driven wakefields at high repetition rates and high efficiencies

These activities will address, amongst other things, some of the key challenges that need to be addressed for future plasma-based colliders

- Schemes to produce 6D- bright electron beams relevant for high-energy physics
- Multi-kHz, high wall-plug efficiency laser drivers
- Stable electron beams over long periods and beam control
- Staging multiple accelerator modules
- Accelerating positron beams

The structure of the collaboration to deliver some of these is being built from bottom-up, building work packages around the main activities. The coordinators (Wim Leemans and Rajeev Pattathil) have also identified experts in the community to lead most of the work packages. The work in this area will be aligned with activities of the ALEGRO consortium, which provides a vehicle for community engagement.

Muon colliders

by D. Schulte and S. Stapnes (CERN)

The muon collider is identified as one of the priorities of the European Accelerator R&D Roadmap, providing a unique path toward high-energy (10+ TeV), high-luminosity lepton collisions.

A muon collider combines precision and discovery reach, competing and/or being complementary to proton colliders at much higher energies. It is expected to be particularly compact as well as cost- and power-effective, providing a sustainable long-term direction for particle physics. An international collaboration, hosted at CERN, has formed to develop the concept; it currently has more than 30 institutional members; the Collaboration Board is chaired by N. Pastrone (INFN).

The collaboration is led by D. Schulte (CERN). A Steering Board, chaired by S. Stapnes (CERN), will liaise between the Laboratory Directors Group (LDG), the collaboration and the study itself. The US Snowmass process generated great interest in the muon collider. The first US universities have joined the collaboration and wider participation is hoped for and expected following the conclusion of the P5 process in 2023.

The aim of the collaboration is to study a 10 TeV option, with 10 ab^{-1}, as well as to explore lower- and higher-energy options. In particular, an initial energy stage might allow an early realisation of a muon collider and could later be upgraded to higher energy; currently, we are considering 3 TeV with 1 ab^{-1}.

In the past, the concept has been developed mostly in the US as part of the Muon Accelerator Programme (MAP). The figure 5 shows this concept as our initial baseline design. The proton complex produces a short, high-intensity proton pulse that hits the target and produces pions. The decay channel guides the pions and collects the produced muons into a bunching and phase rotator system to form a muon beam. Several cooling stages then reduce the longitudinal and transverse emittance of the beam using a sequence of absorbers and RF cavities in a high magnetic field. A system of a linac and two recirculating linacs accelerate the beams to 60 GeV followed by one or more high-energy accelerator rings; e.g. one ring to 300 GeV and one ring to 1.5 TeV. In the 10 TeV collider, an additional ring from 1.5 to 5 TeV follows. These rings can be either fast-pulsed synchrotrons or FFAs. Finally, the beams are injected at full energy into the collider ring. Here, they circulate to produce luminosity until they are decayed; alternatively, they can be extracted once the beam current is strongly reduced. The exact energy stages of the acceleration system have to be developed. Initial target parameters scaled from the MAP design would achieve the integrated luminosity goals within five years of full luminosity operation.

The reviews for the European Accelerator R&D Roadmap and Snowmass did not identify any showstoppers. Furthermore, important progress has been made on both the design and technologies and gives confidence that the scheme can reach its performance goals. However, the muon collider concept is less mature than that for electron–positron colliders, for example, which have already been constructed and studied in great detail. In particular, muons are unstable particles, which creates particular challenges. Further development of the technologies and demonstration of performances are essential. The muon collider key technologies are in many cases well connected with industrial interests, for example in the area of HTS solenoids that are relevant for fusion reactors and for wind-power generators. Other technology synergies include superconducting dipoles with the FCC-hh, targets with neutron, muon and neutrino beam facilities, superconducting RF with the ILC and others, and high-efficiency klystron with CLIC and others.

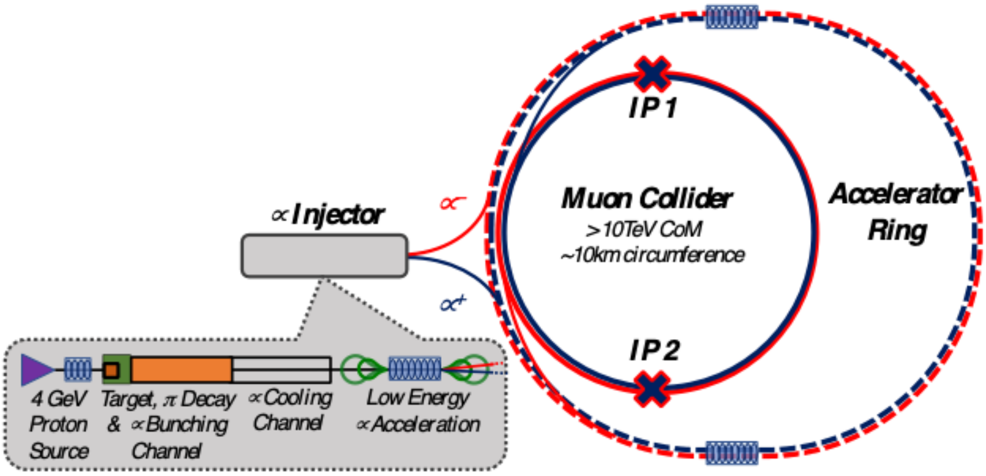


Figure 5: A schematic layout of the muon collider, courtesy of Mark Palmer.

R&D scenarios are described in the Accelerator R&D Roadmap for different funding levels. The goal for the full funding scenario is to provide a Project Evaluation Report to the next update of the European Strategy that addresses the key performance, risk cost and power consumption drivers. The report will also contain some first site considerations. In addition, an R&D Plan will describe a path towards the collider. A key element of this will be a demonstrator containing muon production and cooling. An Interim Report by the end of 2023 will describe the progress toward these goals. These documents will allow informed decisions to be made at the next European Strategy update concerning the future muon collider programme.

The key studies identified in the Roadmap are:

- The **physics potential** has to be further explored; 10~TeV muon collisions are uncharted territory.

- The **environmental impact** must be minimised and at least one **potential site** for the collider identified. In particular, a proposed solution to reduce the neutrino flux density to a negligible level has to be validated.

- The impact of **beam-induced background** in the detector might limit the physics reach and must be carefully studied.

- The muon **acceleration and collision** systems become more demanding at higher energies and are the most important cost and power consumption drivers. The concept and technologies have to be developed beyond what MAP has considered.

- The **muon production and cooling systems** are challenging novel systems and call for development and optimisation beyond the MAP designs.

The collaboration's resources are limited but increasing with the help of the efforts of an increasing collaboration and by connecting to technology development programmes that study and offer solutions well adapted to a muon collider, e.g. within magnet and RF R&D. A prioritised work programme has been established that takes into account the risks for the muon collider as well as the research capabilities and interests of the collaborators.

Energy recovery linacs for power-efficient powerful beams

by J. D'Hondt (Vrije Universiteit Brussel), A. Hutton (JLab), M. Klein (University of Liverpool), J. Knobloch (HZB) and A. Stocchi (IJCLab)

We have a responsibility to reduce the energy footprint of the powerful accelerators used to explore the fundamentals of nature. Accelerating particles will always require a large amount of energy, hence optimal use of this energy is an unavoidable challenge for both our current and, especially, our future colliders. Our field has expressed the ambition to accelerate leptons into powerful beams with high energy and high current. For the FCC-ee collider, a power consumption of 1.4 TWh per year is quoted on the FCC website (it was 1.9 TWh per year in the FCC CDR). For 15 years' operation, this could lead to electricity costs well above 5 BCHF based on current prices.

To accelerate lepton beams, power is passed from the electricity grid to the particle beam. While the grid-to-beam efficiency is reduced by the RF power generator, by the cryogenic plant to keep the cavities cold, by the heat dissipation in the cavities, and by the detuning effects of the cavities, a large fraction of the power is ultimately delivered to the particle beam.

This beam is used in collider experiments. Thereafter, in linear colliders, the beams are dumped and the entire beam power is basically lost, i.e. the power taken from the grid is mostly transferred to the beam dump system. In circular colliders, the beams collide at high frequency, but also emit a large amount of synchrotron radiation. Unlike in linear colliders, the beam brightness is difficult to maintain due to, for example, the many beam–beam interactions each time the beams cross the collision points. Accordingly, circular colliders require a lot of power to compensate for the synchrotron radiation of a less bright beam, leading to limitations on the luminosity that can be achieved.

The 2020 update of the European Strategy for Particle Physics stated: "*The energy efficiency of present and future accelerators […] is and should remain an area requiring constant attention. A detailed plan for the […] saving and re-use of energy should be part of the approval process for any major project*."

Energy recovery systems have been developed to recover almost all of the beam's power before the beam is dumped in linear colliders or before the beam's brightness is lost in circular colliders. The technology for energy recovery linacs (ERLs) has been successfully demonstrated in operation with lower energy and lower current beams, i.e. less powerful beams (power = energy x current). If we can innovate ERL technology to achieve almost full recovery with powerful beams, we will deliver technology that could save about half the power consumption of future Higgs factories. For example, during 15 years of FCC-ee operation at 300 MW, each year's consumption is the equivalent of about 2% of the annual energy consumption of Belgium, a medium-sized European country.

The Snowmass process gave birth to the first ideas for ERL-based Higgs factories. While full scrutiny of these initial thoughts is ongoing, they suggest that, by integrating ERL technology into both linear and circular Higgs factories, one could achieve significantly more Higgs bosons for the same electricity bill. One might even dream of operating an ERL-based Higgs factory in the 27-km LHC tunnel that would produce as many Higgs bosons as a non-ERL-based Higgs factory in a 100-km tunnel.

Accelerating charged particles with warmer superconducting RF (SRF) cavities is a game changer, like bending charged particles with warmer high-temperature superconducting (HTS) magnets. When innovating superconductive materials for high-performance cavities and magnets above 4 K, cryogenics work with helium at atmospheric pressure instead of superfluid helium. In addition to a smaller capital investment to build these cryogenic systems, this translates into a factor of 3 to 4 less power required for their operation. Switching from a cold (2 K) collider to a warmer (4.4 K) collider should therefore be a key goal, with a major impact on the energy efficiency of our science programme. These developments on the SRF cavities, along with improvements to the amplifier efficiency for RF power generation, developments for novel fast reactive tuners dealing with microphonics for the detuning of the cavities, effective handling of higher-order modes with power couplers, developments of high-current particle sources, and others, are captured in an overall "Sustainable Accelerating Systems" R&D programme.

PERLE [1] is a growing international collaboration developing a multi-turn demonstrator facility at IJCLab in Orsay for ERL at high beam currents [2]. The R&D facility is ready to become the leading centre in Europe in our field for developing and testing sustainable accelerating systems that use less energy, require less cooling, have less power losses and recover the beam power. A strong team of experts is being formed in the PERLE collaboration to make this happen in this decade, and collaborators are welcome.

The engine of our curiosity-driven exploration is society's appreciation for the portfolio of technological innovations and knowledge transfer that we continue to realise. Based on 50 years of successful R&D and operation, ERL technology delivers on this front. While ERL technologies require minimal energy consumption to accelerate particles to high energies, the technology offers maximal knowledge transfer to revolutionise applications in key industries, e.g. nanometer-scale semiconductors with photolithography, production of medical isotopes, XFELs, and career paths to industry.

The R&D road ahead to demonstrate high-power ERL is very clear and well documented. The ambition is shared with major accelerator laboratories in Europe, e.g. PERLE at IJCLab and the bERLinPro project at the SEALab facility of the Helmholtz Zentrum in Berlin, and they warmly welcome collaborators to prepare this future together. Developing sustainable accelerating systems is a vital topic for the future of particle physics colliders at CERN and a challenging responsibility that we share as a community. It is essential to demonstrate the performance of these innovative systems during this decade in order to integrate them in a timely fashion into the designs of future Higgs factories or other colliders. With ERL technologies, the future for particle physics looks bright in an energy-efficient way.

Subscribe to the ERL list via https://e-groups.cern.ch/ (use the search option, and search for "erl-roadmap-all" in all e-groups).

[1] PERLE: https://inspirehep.net/literature/1601165

[2] Accelerator R&D Roadmap: https://inspirehep.net/literature/2014192 ; and the extensive overview paper on ERL developments: https://inspirehep.net/literature/2106268

Plenary ECFA meeting reports

Report from DESY

by B. Heinemann (DESY, University of Freiburg)

The **Deutsches Elektronen-Synchrotron (German Electron Synchrotron) DESY**, with its 2700 employees, covers the four research pillars photon science, accelerator R&D, astroparticle physics and particle physics at its two sites in Hamburg and Zeuthen. DESY operates large-scale research infrastructures, is a strong partner in the international research landscape and has several interdisciplinary centres to bring communities together.

The highest-priority project at DESY is the upgrade of the **PETRA III light source to PETRA IV** – an ultra-low emittance (20 pm) machine. The upgrade will encompass a completely new synchrotron and a new 600-m-long experimental hall with new optimised beamlines, and provisions have been made for a future injector based on plasma wakefield acceleration (PWA) technology. A technical design report is in preparation, and a funding decision is expected for 2024; the overall cost is expected to be about 1 billion EUR. Care needs to be taken in the PETRA IV planning to ensure that the future DESY IV booster can again accommodate a **test-beam facility**, as does the present DESY II, serving typically 300–400 users from the worldwide particle, nuclear and astroparticle physics community each year.

The **DESY accelerator division** focuses on R&D for more compact accelerators, and in particular on PWA, with a view to future applications in e.g. industry and medicine. Two facilities – KALDERA and FLASHForward – are world-leading facilities working towards applications in photon science and (later) high-energy physics.

The recently approved **Deutsches Zentrum für Astrophysik** (German Centre for Astrophysics) DZA (of which DESY was one of the main proponents) will tackle the challenges in astrophysics today, with contributions to the Square Kilometre Array (SKA) and the Einstein Telescope (ET), with a strong instrument development programme and a focus on data-intensive computing. The location in Lusatia in Saxony may also be suitable for the ET and could be a third option to be considered together with those in Limburg and Sardinia. A decision on the location of ET is expected for about 2025.

The **DESY particle physics division** serves as a hub for the German community, makes major contributions to international projects, and hosts an attractive on-site experimental programme as well as a world-class theory group. We are developing forefront technology (detectors, computing, accelerators), and we provide infrastructure for national and international researchers (test beam, computing centre, detector assembly facility, etc.).

The **various crises** the world is currently experiencing are also affecting the work in particle physics and in general at DESY. The Russian war in Ukraine has led to a lack of magnet cable suppliers, affecting e.g. the BabyIAXO experiment (see below), and to reduced funding or workforce for e.g. the LUXE experiment and the CMS HGCAL upgrade project. Together with the effects of inflation and increased energy costs, this leads to a very challenging situation faced by the lab and the division.

DESY contributes to a set of **large construction projects together with the German community**, most notably the ATLAS and CMS tracker endcaps and the Belle II PXD2 detector. For the ATLAS endcap, where preproduction is about to start, a system test with 1/8 of an endcap populated with 12 petals and using a realistic mechanical structure is being prepared for 2023.

Similarly, production is beginning in CMS for numerous deliverables, e.g. 1120 PS modules, 16 integrated "Dees", and 5 integrated double-disks. Both the ATLAS and CMS work at DESY is on track for timely delivery to CERN.

For the Belle II PXD2, both half-shells were delivered to DESY in 2022 for commissioning. Unfortunately, a mechanical deformation of the ladders under changing environmental conditions has been observed. Work is under way to solve this issue in order to be on time for delivery of the detector to KEK in early 2023, so that it can be installed for the run scheduled to start at the end of 2023.

The European Strategy for Particle Physics stressed the need for vibrant national labs and their programmes as a complement to CERN. At DESY, the programme of **on-site experiments in Hamburg** is being developed, featuring four experiments.

The "light-shining-through-a-wall" **axion search experiment ALPS II** is fully installed, with all components now fully operational, including the delicate optics. A first calibration signal was observed in November 2022, and a first physics run is planned for early 2023.

The **BabyIAXO** helioscope – a precursor of the much larger International Axion Observatory IAXO – is by now a very strong collaboration, with more than 100 collaborators from 21 international institutions. It can be seen as a follow-up to the CERN axion experiment CAST. The experiment is well advanced, with all technical components designed or even in place (e.g. the mechanical structure and drive system, the prototype micromegas detector system, etc.), except for the magnet. There is unfortunately currently no supplier for Al-stabilised superconducting cables outside the Russian Federation, which are required not only for the BabyIAXO magnet but also for all magnets in the experiments at future colliders. A dedicated workshop on this issue took place in September at CERN, and discussions are ongoing on a potential revival of this technology in Europe. In particular, a detailed plan for handling the situation is being developed between DESY and CERN.

The **Magnetized Disc and Mirror Axion Experiment MADMAX** will search for axions from the dark matter halo. The collaboration has made substantial progress, with a complete conceptual design for its magnet and successful conductor tests at CEA/Saclay. The understanding of the booster could be much improved with a series of prototype tests at CERN with the MORPURGO magnet. The further schedule of MADMAX beyond the prototyping and testing phase depends critically on the availability of funding for the magnet.

The **"Laser- und XFEL" Experiment LUXE** aims to explore QED in the high-intensity regime, and in particular to probe the Schwinger limit using high-power lasers and the European XFEL electron beam. In addition, LUXE will also incorporate an axion-like particle search. The collaboration now comprises 19 international institutions with more than 100 collaborators and has very recently achieved CD1 status at DESY, a prerequisite for attracting additional collaborators and securing the necessary funding.

In the fields of generic detector R&D and technology development, the focus in detector R&D is on silicon pixel detectors and high-granularity calorimeters. DESY also hosts the ECFA Detector Panel. Furthermore, the area of scientific computing is continuously being strengthened, with e.g. the Key4HEP software project for future colliders, and in the fields of machine learning and artificial intelligence, quantum computing and data management. In these fields, DESY is exploiting synergies with photon science wherever possible.

Early-Career Researchers Panel

by the ECFA Early-Career Researchers Panel

The ECFA Early-Career Researchers (ECR) Panel is now concluding its second year, which is a moment of change: the duration of a panel member's mandate is two years, and most of the panel members joined two years ago. Some panel members will be renewing their mandates, while others will be stepping down, thus signalling a significant transition in the panel composition. With this in mind, we would like to warmly welcome the incoming panel members, thank the outgoing panel members for all of their contributions over the past two years, and extend our gratitude to those who are renewing or continuing in their mandates, thus helping to bridge the transition and ensuring that the panel's activities can continue uninterrupted.

In the past six months, the panel has focused on three different directions, representing the past, present and future. For the past, the panel is currently preparing a report on its first two-year period, which will describe the panel's composition, its organisational structure and the work that has taken place. This report will appear soon, is intended for public dissemination and will, we hope, prove useful for both the ECFA and ECR communities to better understand the panel's activities. Moreover, the report should help to welcome the next round of ECR representatives by providing them with a document they can use to understand how to get involved.

The panel has also put significant effort into understanding the present views of ECRs on topics that are particularly relevant to the community: the career prospects of ECRs, and a diverse physics programme. A survey was prepared over several months, undergoing numerous iterations, before it was distributed to the ECR community in September. The survey received 683 responses; the panel would like to strongly thank the community for their enthusiastic participation! In parallel, a reduced survey containing a direct subset of the questions was circulated to the RECFA members, with the intention of helping to understand potential disconnects of opinion between ECRs and senior members of the ECFA community. The analysis of the survey results is ongoing, and it will certainly be an enriching read once the report is public!

Looking to the future, the ECR panel organised a networking event and discussion with invited panellists, which was focused on learning how to build a successful career in instrumentation, both within academia and in industry [link]. This represents one of the concrete actions that the panel is taking to support the ECR community, following the challenges identified in the report on training in instrumentation [link].

Anyone who is interested in following the ECR Panel's activities, or who wants to be notified when the panel releases new reports such as those described above, is encouraged to sign up to mailing list by contacting ecfa-ecr-announcements@cern.ch.

Mid-term report from Spain

by C. Martinez Rivero (IFCA, CSIC-UC)

Particle and nuclear physics in Spain is done in both universities and public research bodies – in this case CSIC and CIEMAT. Some research centres, which depend on regional governments, also participate in HEP: IFAE in Barcelona, ICCUB in Barcelona and IGFAE in Santiago. Finally, LSC in Canfranc, PIC in Barcelona and CNA in Seville also perform particle physics research.

Public funding for particle and nuclear physics depends on the number of projects approved each year by the AEI (Spanish Research Agency). The total amount of euros per year funded in the last three years were 12 MEUR in 2019, 7 MEUR in 2020 and 10 MEUR in 2021. The AEI also allocates predoctoral funding for research students, the final number for HEP being low – 14 students in 2019, 7 in 2020 and 10 in 2021. However, in 2022 the AEI is directly funding the maintenance and operation (M&O) of LHC experiments to the tune of around 2 MEUR.

Ramón y Cajal postdocs are the basic contracts in Spain in order to secure a staff position. The numbers of *Ramón y Cajal* obtained in HEP – and other areas – are very low (7 in 2019, 11 in 2020 and 20 in 2021, the latter including another type of contract called *Juan de la Cierva*). The Spanish HEP community thinks that the Minister of Science and Innovation (MICIN) should fund more *Ramón y Cajal*. The Spanish Excellence Programme (SOMMA), which provides direct funding to some institutes/groups of either 4 MEUR under the Severo Ochoa programme or 2 MEUR under the María de Maeztu programme over four years, counted seven HEP centres in 2019 and in 2022 only two remain (IFT in Madrid and ICCUB in Barcelona).

Finally, related to the new budget for construction and operation costs for Phase 2 upgrade MoUs with the LHC experiments, the MICIN has directly transferred 6.34 MEUR to CERN in 2021 and the same amount in 2022. These are the total quantities needed for the Spanish groups to do all the work assigned to them as part of the Phase 2 LHC upgrades. The HEP community considers this to be an issue of great importance. Furthermore, the RECFA letter sent to the Ministry of Science and Innovation in March 2019 commented that most of the engineers and technicians are hired using project-based budgets; nowadays it seems that new research assistants and specialised technicians will have permanent posts in science institutes.

Mid-term report from Slovenia

by M. Mikuž (University of Ljubljana and Jožef Stefan Institute)

Slovenia is a small (20 000 km^2, 2 M inhabitants) central European country with a GDP about 100 times smaller than Germany or 10 times smaller than Poland. Yet it features a lively HEP community of ~30 experimentalists involved in ATLAS and Belle II, complemented by ~10 theorists. In addition, there is activity in astroparticle (PAO, CTA) and nuclear physics.

Slovenia has been an Associate Member in the Pre-Stage to Membership of CERN since 2017 and joined ECFA in 2018. The first RECFA country visit took place in April 2019. In 2021 Slovenia asked for an extension of its Associate Membership for two years to improve its readiness for full membership, mainly in terms of industrial return. The latest industrial return data indicate a slow but steady improvement, and Slovenia recently moved from being a very poorly balanced to a poorly balanced state.

The definite highlight of Slovenian HEP since the 2019 county visit is the reception of the ERC Advanced Grant in 2020 by Professor P. Križan for the FAIME project, aiming to investigate flavour anomalies in the B-meson sector in the large data sample collected by the Belle II spectrometer.

Another important Slovenian contribution to HEP is the acquisition and commissioning of VEGA, the first EuroHPC computer, in April 2021. The HEP computing group played the leading role in designing the architecture, in procurement, and then in commissioning. VEGA, in its commissioning phase, provided substantial opportunistic resources in the order of the integral ATLAS pledge to WLCG.

In summary, Slovenian HEP is carrying on with the good work observed during the initial RECFA visit. Most of the recommendations from the 2019 RECFA visit have been addressed adequately. In the coming years, concerted efforts will be needed in order to accomplish full CERN membership status in 2024.

News from the European labs

Lab Directors Group

by D. Newbold (STFC Rutherford Appleton Laboratory)

The European Laboratory Directors Group (LDG) brings together representatives of the major national laboratories in Europe, along with CERN, with the purpose of: ensuring communication and coordination of research plans, investment, and priorities; and furthering discussion on points of common interest.

In addition to inter-laboratory discussions, at its last meetings the LDG has received presentations on the progress of the ILC project, both in technical areas and in the definition of potential international governance structures, and presentations on the work and future plans of the INSPIRE-HEP project.

In December 2022, following approval by CERN Council, the LDG welcomes the accession of Daresbury Laboratory (UK) to the group. Daresbury has a long history of collaboration in particle accelerator technology for colliders, light sources, and other applications. It is also a main hub for engineering towards detectors and instrumentation in the UK, and is currently engaged in production of APA modules for the DUNE experiment. Daresbury will be represented on LDG by Professor Jim Clarke.

We also welcome Professor Franck Sabatie as the new representative of Saclay. We thank Professor Lenny Rivkin for his contributions to LDG as past chair and in his more recent role as SPC chair.

Global Laboratories Forum

In order to maximise the engagement of the national laboratories with the wider particle physics community, and to further links between European laboratories and those outside Europe, LDG proposes to hold a two-day Global Laboratories Forum in July 2023. This event will bring together representatives of laboratories worldwide, to discuss current plans, and future opportunities and challenges. Immediately following the Forum, we will hold the first Community Workshop on the Accelerator R&D Roadmap, at which the Coordination Panels will provide updates on progress and hold discussions with the particle physics user community about future directions and the link to future particle physics research goals. This event will be open, in hybrid format, to the entire particle physics community

News from Gran Sasso National Laboratory

by R. Antolini (LNGS)

Figure 6: The XENONnT TPC in the cleanroom before installation underground, with one of the PMT arrays in the foreground. Credit: the XENON collaboration.

Some great new features have come about in our facilities in recent months.

The decommissioning phase 1 of the Borexino experiment ended successfully with the extraction and removal of the 1300 tonnes of liquid scintillator, closing a scientific path made of high-level discoveries in solar neutrino physics, as the first measurement of the neutrino flux produced by the CNO cycle.

At the same time, the infrastructure supporting the new Ion Beam Facility, named for Enrico Bellotti, has been completed. Another important step for the project is the completion of the installation and commissioning of the 3.5 MV singletron™ accelerator that, in the first phase, will be dedicated to nuclear astrophysics measurements.

In July the XENON collaboration published the results of the first data set acquired with the new XENONnT detector (5.9 t of target mass), which showed the lowest background ever obtained in a direct dark matter experiment, five times smaller than its predecessor XENON1T. The excess at low energy previously observed in the XENON1T can therefore most likely be explained as traces of tritium.

The LEGEND 200 experiment searching for neutrinoless double beta decay completed the installation of a large part of the HPGe detectors and electronics and just entered the commissioning phase. The first physics run will start in a few weeks.

News from IRFU

By F. Sabatié (IRFU)

Experimental nuclear physicist Franck Sabatié has been announced as the new Director of the French CEA's Institute for Research into the Fundamental Laws of the Universe (IRFU), effective from 19 September 2022, succeeding Anne-Isabelle Etienvre, now a cabinet member of the French Ministry for Higher Education and Research.

IRFU, one the largest CEA institutes, has scientific activities ranging from particle, astroparticle and nuclear physics to astrophysics and cosmology, supported by strong technical departments in the areas of accelerators, superconducting magnets, system engineering, detectors, electronics and computing. Jointly with the CNRS, IRFU also develops and operates GANIL in Caen, a state-of-the-art nuclear physics accelerator facility.

Highlights from IJCLab – autumn 2022

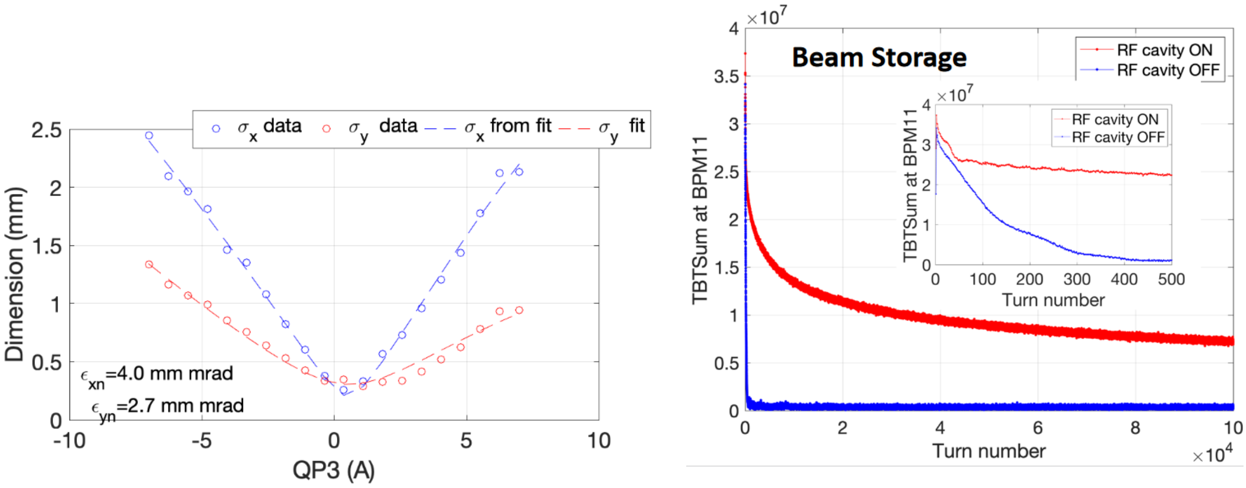
by A. Stocchi (IJCLab)

ThomX is a new-generation compact Compton source, producing high-flux X-ray in the range of 45–90 KeV from the interaction of a 50 MeV electron beam and a laser beam from an optical multipass Fabry–Perot high-finesse cavity. It is currently being commissioned at IJCLab. The linac of ThomX has been being commissioned for almost one year and recently the electron beam was successfully injected in the storage ring.

Below are two short pieces of news on one accelerator project that is starting (PIP II) and one that is ending (ESS):

- For the contribution to PIP II, we have worked on the design of spoke cavities in collaboration with FNAL and the cavity preparation (surface treatment). We are already in the phase of testing the performance/qualification of the first cavity received from Zanon.
- For ESS, 13 single spoke cavity cryomodules have been manufactured, 12 have been delivered and 1 is still being assembled at IJCLab. All valve boxes (23) for cryogenic distribution lines have been delivered to Lund. The project is expected to end mid-2023.

After the beam characterisation in the storage ring, the next step is the production of the Compton back-scattered X-ray beam.



Left: beam characterisation at the end of the ThomX linac. Right: electron storage in the ring with and without RF cavity.