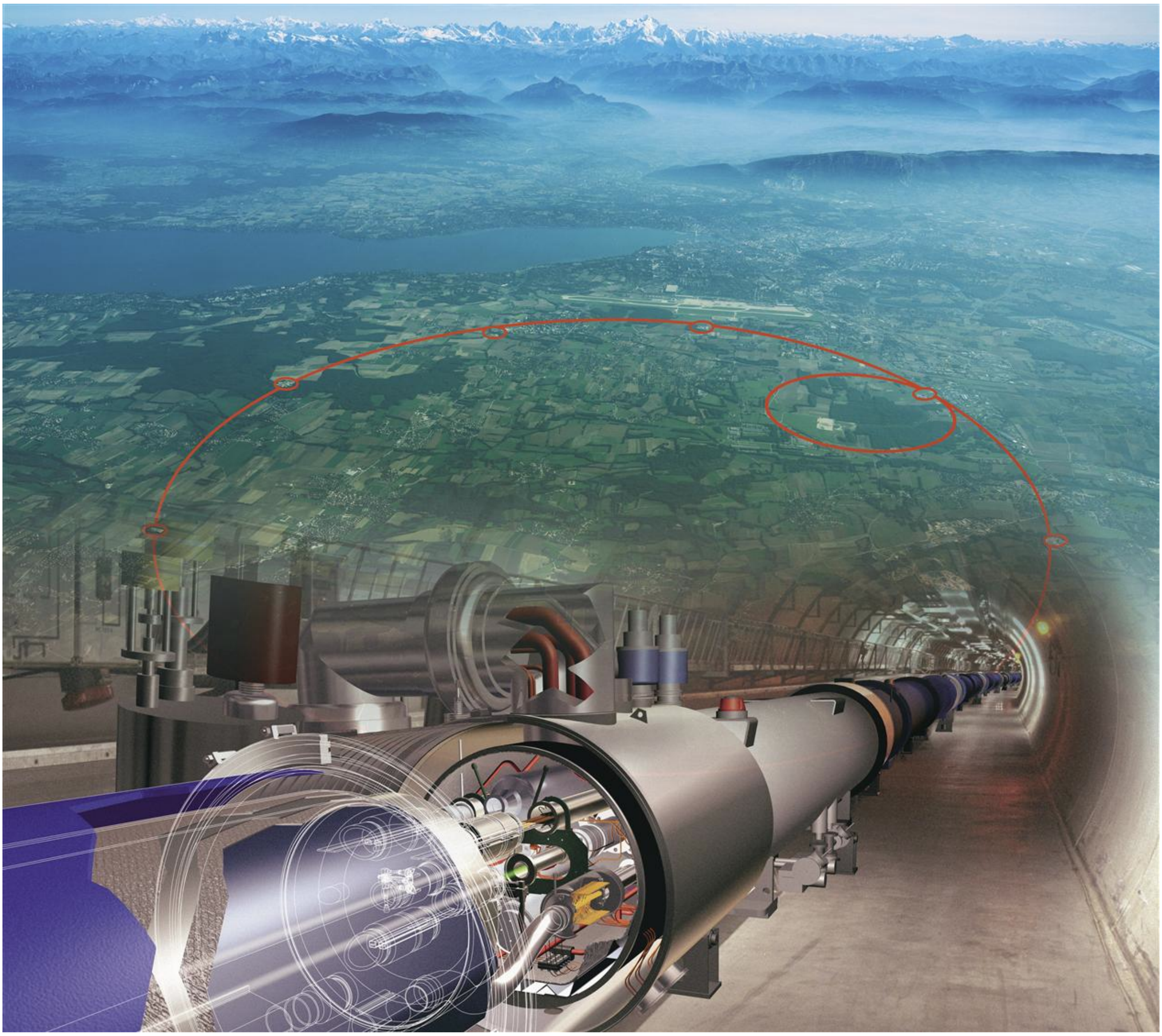
ECFA
European Committee for Future Accelerators

ECFA Newsletter #5



Following the Plenary ECFA meeting, 13 July 2020
https://indico.cern.ch/event/933318/
Summer 2020

On 13 July 2020, we welcomed ECFA members for our first meeting after the update of the European Strategy for Particle Physics (ESPP)[1] and our first ever Plenary ECFA meeting held entirely by videoconference. Initially scheduled to take place at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, the meeting was switched to remote participation due to the global travel restrictions in force. The agenda was also substantially reduced to focus on the standing items for Plenary ECFA.

Earlier this year, the planned RECFA country visits to Serbia, France and Ukraine were postponed. Nevertheless, via remote meetings, Restricted ECFA was proactive in preparing initiatives in response to the updated ESPP. During these meetings, we gave priority to those topics that will enhance the readiness of ECFA to help our research community when we emerge from the COVID pandemic.

On the subject of major research facilities for particle physics, the updated ESPP indicates priorities for the immediate, medium- and longer-term future. The highest priority is for the full exploitation of the (HL-)LHC; the HL-LHC being the first machine in line as a future collider at the energy frontier. Recent innovations in instrumentation, software, computing, analysis techniques and theoretical reasoning have unlocked several new avenues for physics research at the LHC that were previously thought unreachable. The preparation of our community and organisations to effectively accommodate novel explorations at the (HL-)LHC remains the key priority for the field, including continuous support for the essential upgrades of all four major LHC experiments.

Another key priority is indicated by the support expressed for long-baseline neutrino projects in both the US and Japan. The neutrino platform at CERN is a key asset for European participation in these projects. As the third key scientific priority for our immediate future, support is also expressed for research programmes beyond colliders that aim to have a typically very specific but high impact in the field. In general, these relate to the edge of our observable phase-space, with very massive and/or very weakly interacting particles that connect the Standard Model to a hidden sector beyond the Standard Model.

For the medium-term future and on a global scale, a Higgs Factory is the highest priority collider beyond the HL-LHC. At this stage, the European particle physics community did not decide on the exact type of Higgs Factory to build from among the various options being studied, but it is clear that we all have to work together to realise this aim.

In the longer term, the major ambition for a new collider in Europe, i.e. at CERN, is to move the energy frontier with a 100 TeV hadron collider. Therefore, the priority at this stage is to investigate the feasibility of such a collider as a milestone on the road towards the next Strategy update. And surely, if a 100 TeV hadron collider would be feasible, the infrastructure would be able to host a Higgs Factory as a first stage. To support our ambitions, we need to strengthen R&D for accelerators, and to develop roadmaps for both accelerator and detector R&D in Europe.

Last but not least, we need to adjust our organisational approach in order to achieve the above goals. In order to make our moonshot ambitions a reality, careful consideration of societal, environmental, career and educational aspects at the core of all of our activities is more relevant

[1] https://europeanstrategyupdate.web.cern.ch/welcome

than ever. Our strong ambitions will undoubtedly face major challenges on these fronts. But if our ambition gives rise to problems, it should be our ambition to find solutions as well.

Together with many of you, ECFA contributed to the Strategy debates in the community by holding open sessions on dedicated topics over the last few years,. Now that the Strategy has been updated, ECFA will continue its efforts to discuss accelerator technologies for future colliders and other particle physics experiments.

Additionally, in order to respond to the priorities of the ESPP, ECFA is launching new initiatives and strengthening its ongoing activities. Addressing a major priority in the updated ESPP, ECFA has acknowledged a need for the experimental and theoretical communities involved in Physics studies, Experiment designs and Detector technologies at future Higgs Factories (PED@HF) to join forces. ECFA is supporting a series of workshops aiming to share challenges and expertise, explore synergies between the efforts of these communities and respond coherently to this priority in the ESPP. Previously, ECFA supported Aix-les-Bains-type workshops to bring the community together on the subject of the upgraded HL-LHC experiments. The upcoming PED@HF workshops will prepare the community for the next Strategy update or the moment when concrete decisions need be made regarding a Higgs Factory.

The ESPP calls upon ECFA to coordinate the development of a Detector R&D Roadmap for Europe. This roadmap will include a diversified R&D portfolio to address the future research programme mentioned in the ESPP with both focused and transformational R&D. The aim is to have the Detector R&D Roadmap available by summer 2021 with a view to guiding the national and international actions that support the R&D process in Europe. A Detector R&D Roadmap Panel, chaired by Professor Phil Allport (University of Birmingham), will assist ECFA in developing and organising a major consultation with the particle physics community and with adjacent disciplines with whom our technologies overlap.

The many synergies between astroparticle, nuclear and particle physics were addressed in the first Joint ECFA-NuPECC-APPEC Seminar (JENAS) at Orsay in 2019. Following the event, several expressions of interest were received on topics where synergies among APPEC, ECFA and NuPECC could strengthen the project. The topics range from nuclear physics at the LHC and machine learning for detector designs, to gravitational waves for fundamental physics and bringing together the dark matter community across disciplines, and as well the ambition to develop storage rings to search for electric-dipole moments of charged particles. Based on this success, and supported in the updated ESPP, a call was launched for candidate venues for the next session of this three-day biennial JENAS event. The Joint Seminar is intended to inform our communities about each other's scientific, technological and organisational challenges and opportunities. Proposals should be communicated to the three chairs of APPEC, ECFA and NuPECC, and reach us no later than 21 September 2020.

In parallel with the main Strategy debates, ECFA took the initiative to invite around 180 early-career researchers to hold their own debate in November 2019. Their report[2] was widely appreciated and was presented to the European Strategy Group at its decisive meeting in Bad Honnef in January 2020. Embracing this productive experience, and supported by the updated

[2] https://inspirehep.net/literature/1779145

ESPP, ECFA has initiated the creation of a permanent ECFA Early-Career Researcher (ECR) Panel. The objective of the ECR Panel is for its members, PhD students and postdocs in ECFA countries, to discuss all aspects that contribute in a broad sense to the future of the research field of particle physics. In its advisory role to ECFA, the panel will report to ECFA on a regular basis. Members will participate as individuals but should aim to represent the views of early-career researchers in particle physics in the country that nominated them. With a view towards having an open relationship with ECFA, a delegation from among the panel members will be assigned by the panel as observers to Plenary ECFA meetings, and one member will be assigned by the panel as an observer to Restricted ECFA meetings.

Regarding organisational matters, a review of the list of major laboratories represented in ECFA is ongoing. Since 2009, the ECFA Terms of Reference have indicated the representation of three major laboratories as observers to Restricted ECFA, i.e. CERN, DESY and the Frascati National Laboratory. A call for additional interested laboratories has been launched. Written proposals should be communicated by the director of the laboratory (or equivalent) to the Chair and Scientific Secretary of ECFA and reach us by 21 September 2020 at the latest. The proposals will be discussed in Restricted ECFA, and a plan to potentially adapt the list in the ECFA Terms of Reference will be presented for endorsement by Plenary ECFA. The following benchmarks will be used in our deliberations of the proposals received:

- the laboratory is hosted by (at least) one of the ECFA member countries;
- the European research community collaborates on particle physics experiments at accelerators or accelerator structures that are operational today at the laboratory, or are under construction;
- cutting-edge accelerator R&D towards colliders for particle physics is currently present at the laboratory, or the infrastructure for this is under construction;
- an extensive and demonstrable European user community is present at the laboratory such that lab-to-community communication, provided by ECFA, is essential for the proper functioning of the laboratory (lab-to-lab communication remains the purview of the Laboratory Directors Group).

All four of the benchmarks listed above will be considered in the discussion and thus should be addressed in the proposals.

In this fifth ECFA Newsletter, you will find reports on the talks presented during the Plenary ECFA Session on 13 July, as well as two dedicated articles on important activities related to accelerator R&D and future colliders.

As we, together with society at large, continue to face the COVID pandemic, please take care of each other and support each other more than ever in these unconventional times!

Jorgen D'Hondt, ECFA Chair
Carlos Lacasta, ECFA Scientific Secretary

Initial views on the European Strategy implementation

by Fabiola Gianotti (CERN Director-General)

The 2020 update of the European Strategy for Particle Physics (ESPP) provides a realistic and prudent approach to setting ambitious and visionary scientific objectives. It lays the foundations for a bright future for particle physics in Europe, within the global context of the field.

Implementation of the ESPP has started at CERN, and a few examples are listed below. The full exploitation of the LHC, including the high-luminosity upgrades, remains CERN's highest priority. Accelerator R&D studies are being reinforced, in particular in the domain of superconducting high-field magnets. The feasibility study for the FCC (Future Circular Collider), which should be completed by the next Strategy update, will focus on the tunnel (high-risk zones, environmental aspects, etc.) and on the main technologies for the e^+e^- and pp colliders. To maintain CLIC as an option for a future collider, as recommended by the ESPP, resources will be allocated to continue work on key accelerator technologies. An effort on muon colliders is starting with the goal of addressing the main challenges (neutrino background, muon source and cooling, accelerator and collider rings, etc.) and of developing the design of a demonstrator by the next ESPP update. Physics Beyond Colliders activities will be strengthened. Work at the Neutrino Platform continues, in support of the European community involved in long-baseline projects in the US and Japan. A Quantum Technology Initiative has been launched at CERN, in collaboration with similar efforts in CERN's Member States and beyond, to develop innovative computing technologies for future projects.

The ESPP is the result of two years of intense and successful efforts by our community to prepare and discuss high-quality scientific and other input. Similarly, its implementation will require the work, dedication and enthusiasm of the full community.

Reports from laboratories in Europe

Reports from some of the major laboratories in Europe, namely CERN, DESY and Frascati, are standing items on the agenda of Plenary and Restricted ECFA meetings. These reports inform the community of new developments and opportunities and, as per the mandate of ECFA, stimulate the culture of collaboration. When relevant, the management of other laboratories in Europe can contact the ECFA Chair to find out whether an appropriate slot is available on the agenda of a future meeting to make a report.

CERN – presented by Fabiola Gianotti (CERN Director-General)

Activities at CERN restarted in mid-May, based on a gradual and prudent ramp-up plan supported by stringent COVID-19-specific health and safety measures, with priority given to Long Shutdown 2 (LS2) work and the upgrades of the accelerators and experiments.

LS2 and upgrade activities were progressing mostly on schedule until CERN moved to the so-called "safe-mode" period in mid-March. As of July 2020, the LHC Injectors Upgrade (LIU) project is more than 95% complete and hardware commissioning of Linac4 and the Booster has started. Excellent progress was also made in recent months with the High-Luminosity LHC (HL-LHC) project. As an example, in June, a 60-metre-long demonstrator for the new electrical transmission lines was successfully tested (see picture). The line is a 90-mm diameter MgB_2 superconducting cable, able to carry more than 100 kA at 25 K. The upgrades of the experiments are also progressing well, with a tight schedule for the ATLAS muon spectrometer New Small Wheels (NSW) and the LHCb VELO and Scintillating Fibre tracker. Physics analysis activities continued at a very intense pace during the safe-mode period, and very interesting results were prepared for the ICHEP2020 conference in late July and early August. The new schedule for the start of Run 3 is being discussed with the experiments and should be finalised in November.

The 60-metre-long demonstrator of the superconducting electrical transmission lines for HL-LHC during testing in the SM18 hall at CERN.

CERN has completed its Environmental Report for 2017-2018, which, for the first time in history, will be released publicly.

DESY – presented by Joachim Mnich (DESY Research Director)

Since May 2020, DESY has begun to restart all accelerators on site. Even in July, a large fraction of the DESY staff was still working at home. Several projects were set up to help fight the COVID-19 pandemic, among them the structural analysis at PETRA of bio-molecules that are potentially relevant for drug design.

The European XFEL has now been in operation for about three years, providing lasing in three FELs, with very flexible bunch patterns and timing structures. With the PETRA IV project, for which a TDR is expected by the end of this year, a plan for a synchrotron light source at the diffraction limit has been devised. The KALDERA project – a drive laser for laser plasma acceleration with a repetition rate of 1 kHz and an average power of more than 3 kW – will enter its phased construction in 2020.

DESY, together with all the Helmholtz centres, underwent a strategic evaluation in January 2020, the result of which sets the scale for the lab's base funding in the years 2021-27. DESY particle physics received the highest possible evaluation result, being considered excellent in all aspects of the evaluation.

The on-site experiments ALPS II, BabyIAXO and LUXE are taking shape. The installation of ALPS II in the former HERA tunnel is progressing well, and the first data taking is expected for 2021. BabyIAXO could be ready for first data in 2024. The "Laser- Und Xfel-Experiment", LUXE, in the European XFEL tunnel has now gathered a large international collaboration of 13 institutions (and growing) and is currently preparing a CDR.

The ongoing installation of dipoles for ALPS II in the former HERA tunnel at DESY.

National Laboratory of Frascati – presented by Pierluigi Campana (LNF Director)

The Lab started the recovery of operations in early May after the strict lockdown of March and April. The main goals were to restart activities at the DAFNE Linac (for PADME) and at SPARC_LAB. Gradually, technical and scientific staff achieved the target of having hardware checked and warmed up during June and delivering beams by early July. The pre-COVID priority (i.e. having DAFNE colliding for Siddharta2) was swapped with PADME data-taking until the end of October, to optimise the schedule. In the same period, construction activities for the ATLAS NSW never stopped, although they proceeded at a reduced rate due to a lack of delivered materials. The chamber assembly will in any case be completed by next September. Presence at the Lab is about 50% of the workforce. During this period, the preparation of the EuPRAXIA proposal for the ESFRI roadmap was completed, and the submission deadline of 9 September will be met. The Collaboration Agreement, signed by about 40 large research institutions throughout Europe, is also ready to be submitted to ESFRI.

Scheduled mid-term reports from member countries

After each Restricted ECFA country visit, a report is issued to the executive policy-makers in the country, typically the minister responsible for science, research and/or education. These reports are public and available on the ECFA website. Because the period between two visits to each country is generally seven years, a mid-term report is scheduled at Plenary ECFA meetings to verify and discuss the progress made with the aspects raised in the reports.

Belgium – presented by Nick van Remortel (University of Antwerp)

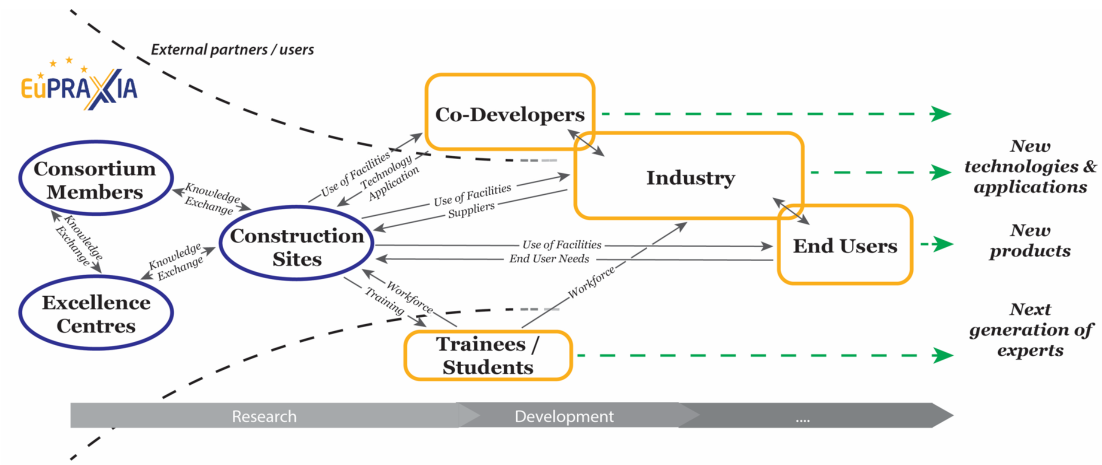
Belgium is one of the founding Member States of CERN and has a longstanding tradition in experimental and theoretical high-energy and nuclear physics. Due to the absence of an overarching organisational structure, our research programmes are driven by a core group of eight universities. In Flanders, these are the Universities of Antwerpen, Gent, Vrije Universiteit Brussel and Katholieke Universiteit Leuven. In Wallonia, these are the universities of Liège and Mons, Université Libre de Bruxelles and Université Catholique de Louvain. The overall funding and personnel status is very positive, with significant growth in both the number of researchers and funding and a corresponding diversification of our research activities. Our experimental activities are balanced over four main domains: collider physics, astroparticle and neutrinos, gravity, and nuclear. Our experimental and theoretical activities are also in equilibrium and provide mutual support to one another. In the past three years, four new experimental programmes have started, with a notably strong surge in the fields of astroparticle and gravitational wave physics. There are however, a few imbalances that require our attention. In the past three years, the total scientific personnel increased by 20% to a total of 325. This growth is not however reflected in the number of technical staff in our labs, which has decreased over the past ten years to a critically low level of 22 people. The reason for this decline is the lack of investment by universities and funding agencies in long-term technical support for our activities. The age profile of our permanent academic staff is young and balanced, except for in terms of gender, since female permanent positions are a small minority of 14%, despite well-established mechanisms in our academic recruitment policies to rectify this. Belgium has for a long time been a poorly balanced country in terms of industrial return from CERN supply and service contracts. A recent initiative to establish an industrial liaison office aims to improve this situation, but will need more overall support to mature properly.

A European Plasma Research Accelerator with Excellence in Applications (EuPRAXIA)

by Maria Weikum (DESY, Project Management EuPRAXIA Design Study), Ralph Assmann (DESY, Coordinator EuPRAXIA Design Study) and Massimo Ferrario (INFN, Chair Collaboration Board EuPRAXIA Design Study)

RF accelerator technology has been a major success story over the past 90 years, enabling the development of complex large-scale machines and applications in a variety of fields from high-energy physics and photon science to medical technologies and industrial tools.

With more than 300 000 machines in use, accelerator-based technologies have been established as essential instruments all over the world today and will continue to play important roles in the future, as several of the scientific roadmaps of European and international communities demonstrate. The recently published 2020 Update of the European Strategy for Particle Physics by the European Strategy Group, for example, proposes clear challenges and development goals for the near- and long-term future of accelerators in particle physics. It emphasises in particular the importance of innovation in accelerator technology, listing it as "a powerful driver for many accelerator-based fields of science and industry" with "technologies under consideration includ[ing] high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures" and emphasising the need to define "deliverables for this decade [...] in a timely fashion"[1].



Concept of EuPRAXIA as an Open Innovation Research Infrastructure in Europe, advancing compact accelerator technologies, including plasma accelerators, from the research phase into the development and exploitation phases (reprinted from M.K. Weikum et al 2019 J. Phys.: Conf. Ser.1350 012059).

The EuPRAXIA ("European Plasma Research Accelerator with Excellence in Applications") project focuses on such high-gradient accelerating technologies and thus comes at an excellent time to

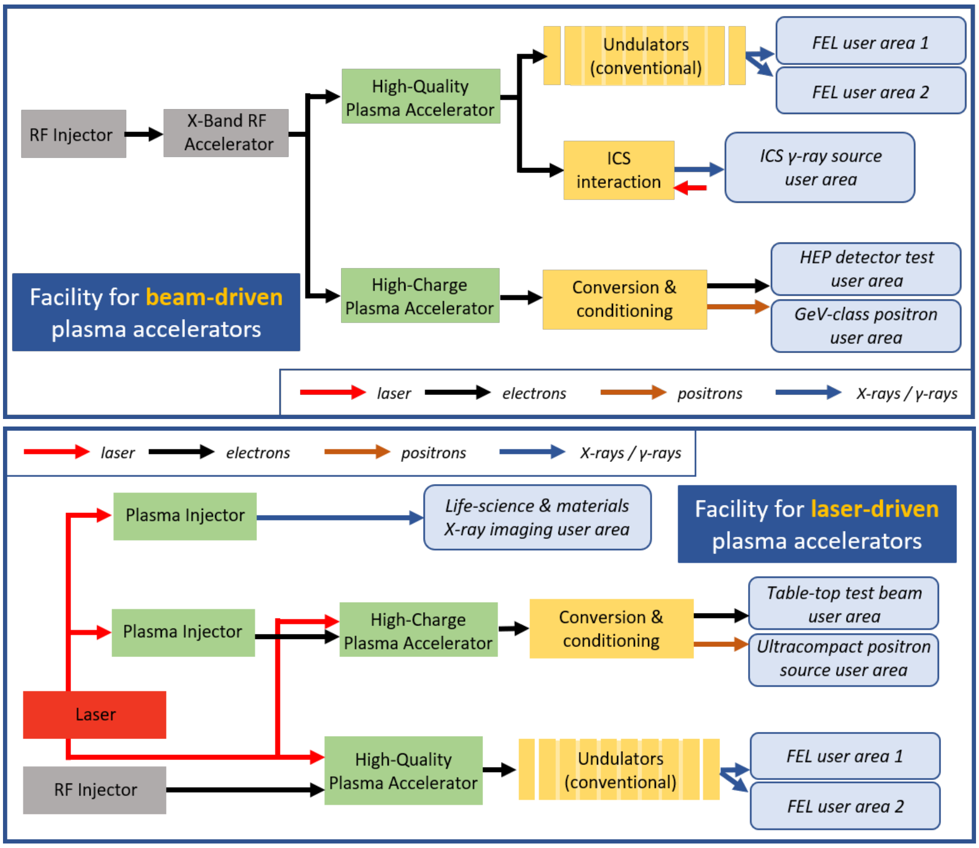
[1] https://europeanstrategy.cern/european-strategy-for-particle-physics

fulfil some of the challenges raised by this Strategy update. By combining plasma wakefield acceleration with compact X-band RF accelerators, this technology proposal not only foresees a large potential for accelerator R&D over the next ten years, but also promises to drive forward a possible next generation of ultra-compact accelerators with their own varied range of applications.

EuPRAXIA started as a conceptual design study for a novel research infrastructure based on plasma accelerator technologies in 2015 and concluded last year with the publication of a Conceptual Design Report[2].

With contributions from 243 researchers and more than 40 partner institutions, it proposes the construction of a distributed accelerator facility that offers:

1) improved performance compared to current state-of-the-art plasma wakefield accelerators with electron energies of 1 to 5 GeV and a beam quality approaching that of purely RF-based machines,
2) a significant reduction in size and possible savings in cost over state-of-the-art RF-based accelerators, and
3) varied applications for existing and emerging accelerator user communities in Europe.



Schematic machine layouts of the two EuPRAXIA construction sites (reprinted from the EuPRAXIA Conceptual Design Report, 2019, accepted for publication in EPJ-ST).

[2] The Conceptual Design Report is available at http://www.eupraxia-project.eu/.

To realise these goals, the design combines well-established solutions, such as in beam transport, diagnostics and undulator technology, with improved methods and novel concepts developed during the study, many of which have been peer-reviewed and published in high-impact journals (e.g. Ferran Pousa et al. Phys. Rev. Lett. 123, 054801 (2019) and Andre et al. Nat. Comm. 9, 1334 (2018)). For the acceleration stages themselves, six different technical options have been selected and are foreseen to be prototyped as part of the technical design, ranging from a very compact single-stage, all-plasma beamline to larger setups using one or several plasma targets as energy boosters to an RF-accelerated electron beam.

The EuPRAXIA concept proposes two main facilities to be constructed. The first site will be based at the INFN Laboratori Nazionali di Frascati in Italy and will be focused on beam-driven plasma acceleration. Housing an X-band accelerator up to 1 GeV combined with plasma accelerator stages to boost energies up to 5 GeV, the facility will be capable of running an X-ray free-electron laser, while also offering applications, such as a GeV-scale positron source, a compact inverse Compton scattering-based photon source, and a "table-top" test beam station for particle physics detectors. The second major EuPRAXIA site, on the other hand, will be based on laser-plasma acceleration and its final location will be decided by 2025 from among a set of several outstanding facilities in Europe. Although also combining RF and plasma technology to develop a robust machine design, the centrepieces of this site will be a laser system with up to 1 Petawatt peak power and a 20 to 100 Hz repetition rate, designed in collaboration with laser institutes and industry with the potential to upgrade to kHz operation in the future. The laser-driven EuPRAXIA construction site will be focused in particular on making use of the short acceleration distances in laser wakefield acceleration and provide a compact betatron-based photon source together with positron and electron beams for material and diagnostics studies. A free-electron laser is also foreseen as a larger-scale application.

3D-rendering of the EuPRAXIA construction site at INFN-LNF. The design process of the building has recently started, it will have dimensions of 134m x 35m with a potential extension added at a later point (image credits: Simona Incremona, General Services and Technical Division).

With the implementation of these two facilities envisaged to be completed only around 2027 to 2031, they are complemented by a set of excellence centres and clusters of expert institutions across Europe. The former in particular are foreseen as key R&D facilities that are based on existing technical infrastructures. As these centres contribute significantly to the development, testing and prototyping of new technologies to be integrated in the construction sites, but in parallel also gain from the knowledge and lessons learned across the entire infrastructure, this model thus allows the integration of national investments in the field of compact accelerator R&D very synergistically into the wider European concept.

Since the completion of the funded design study last year, the EuPRAXIA collaboration has prepared the next phases of the project. An important milestone in this context has been the negotiation of a new consortium agreement, organising the preparatory phase and technical design. This agreement is now in the signature phase and, starting in September this year, it is expected to comprise 52 organisations from fifteen countries as Members and Observers. A second major endeavour will be EuPRAXIA's application to the ESFRI Roadmap Update 2021. This proposal is being prepared at the moment and will see Italy as the lead country with additional political support from several other EU member states.

In summary, the European research infrastructure EuPRAXIA, with its large-scale consortium, will allow the advancement of critical accelerator R&D on highly compact accelerators, as requested in the 2020 Update of the European Strategy for Particle Physics; it will continue to bring together existing European infrastructures in this domain; it will establish the first pilot applications for plasma accelerators; it will strengthen the links with the important European laser industry; and it will build two scientific flagship projects. One construction site will be in the metropolitan area of Rome in Italy and will deliver critical and much needed photon science capabilities for research into materials, bacteria, viruses and health in this region. The high-tech EuPRAXIA innovation project can thus drive scientific advances in Europe with medium electron beam energies and can contribute to sustainable economic development with highly qualified jobs and possible spin-off companies, while being a critical stepping stone to future particle physics colliders based on plasma acceleration.

Electrons for the LHC – on the update of the LHeC CDR on Physics, Accelerator and Detector

by Oliver Brüning (CERN) and Max Klein (Liverpool) – for the LHeC/FCC-eh Study Group

In 2012, at the request of ECFA, a 600-page report [*1206.2913*] was released on the design of a 60 GeV electron accelerator for collisions with the LHC hadron beams. This opened the way for the LHeC, a next generation electron-hadron (p,A) collider, for extending the energy frontier in deep inelastic scattering (DIS) into the TeV region, beyond HERA. So far, the LHC has not found new symmetries or particles leading beyond the standard gauge theory. The strategic question in this situation is how we may thoroughly challenge current, incomplete knowledge with a diverse programme. The near-term possible steps for energy frontier particle physics to progress, prior to a next generation hadron collider, are to build a new electron-positron collider to study the Higgs boson and to realise an electron-hadron collider for sustained discovery and precision with the LHC. The latter is the topic of the 400-page LHeC paper, which was just released [*2007.14491*]. It updates the 2012 CDR, accounting for a decade of new developments in physics, mainly at the LHC, while also profiting from and stimulating progress in detector and accelerator technology. It is dedicated to ep/eA at HL-LHC but advances also the development of the FCC-eh.

Discovery in Deep Inelastic Scattering

DIS is the most appropriate process for exploring the nature of matter, and the LHeC is its deepest possible manifestation. It thus constitutes an instrument with which the theory of strong interactions may be questioned principally. Despite its major successes, QCD has no proof of confinement, no dynamical reason for quarks to exist, no explanation of why there are four heavy quarks, and the transition of fractionally charged quarks into jets is purely phenomenological. The reach of the LHeC and its huge luminosity may thus lead to genuine surprises. An example prospect described in [*P.Yock, Physics Essays 33, 2 (2020)*] is the search for highly charged particles that would restore compliance with Newton's hypothesis of self-similarity and simplicity, which is violated seemingly by the so-far innermost quark layer of matter.

The LHeC extends the kinematic range of DIS to momentum transfers squared, Q^2, up to 1 TeV^2, and from small Bjorken $x \sim 10^{-6}$ to 1, at 2-3 orders of magnitude larger luminosity than HERA. With unprecedented precision, it resolves the partonic structure of the proton for the first time, completely lifting all previous symmetry assumptions in the derivation of parton distributions and ending the dependence on phenomenological nuclear and higher twist corrections. It will decisively establish a new state of matter, non-linear parton interactions in dimensions below 0.1fm, should that exist. This would prove the standard DGLAP parton evolution equations to be a linear approximation only, with profound consequences for any QCD prediction for the LHC and a future 100 TeV hadron collider. This will establish or contradict the saturation of gluons for which the energy of HERA was too small. By measuring α_s to 0.1% accuracy, it will challenge the lattice QCD predictions and resolve long-standing questions about the universality of the strong coupling. Searches for instantons, inconclusive at HERA, may lead to the discovery of topological features of QCD.

Discoveries may be possible in the anomalous top quark sector or with precision electroweak measurements. Due to the clean final state, absence of pile-up and high energy, the LHeC has quite a potential for discovery beyond the SM. Prominent examples for discovery enabled with ep are heavy neutral leptons (or sterile neutrinos) that mix with the electron flavour, dark photons below the di-muon threshold, which are notoriously difficult to detect in other experiments, long-lived new particles in general or new physics scenarios with a compressed mass spectrum, such as SUSY electrowikinos, and heavy scalar resonances with masses around and below 500 GeV, which may exist but literally be buried in "hadronic noise" at the LHC.

Joint hh+eh Physics and the Higgs at the LH(e)C

The HL-LHC may discover new physics, perhaps as an onset of Contact Interactions for which high-x parton distributions have to be known independently and reliably. It will surely become a facility for high precision QCD and electroweak measurements. Both for the interpretation of new phenomena, including a substantial extension of the search range (from typically 50 TeV to 80 TeV for contact interactions enabled by ep), and for exploiting the measurement potential, of e.g. the W boson mass or the weak mixing angle, the LHeC QCD and PDF input is indispensable. A special chapter of the updated CDR presents initial studies of the interrelation of ep and pp, discussing also the relation of eA with heavy ion physics at the LHC.

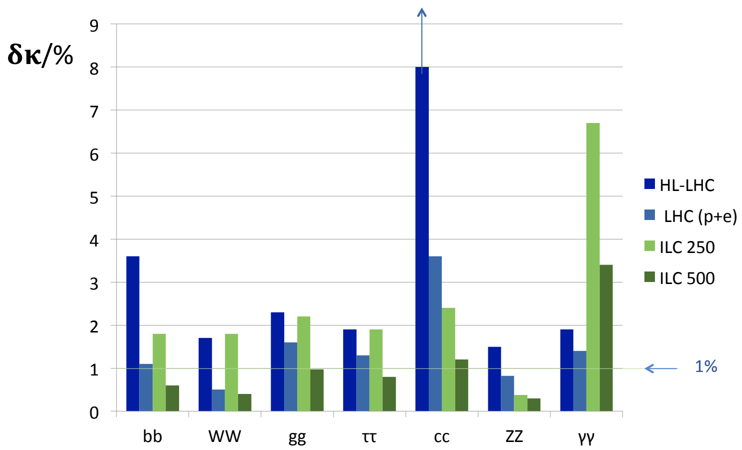


***Figure 1**: Results of prospect evaluations of the determination of Higgs couplings in the SM kappa framework for HL-LHC (dark blue), HL-LHC with LHeC combined (p+e, light blue), ILC 250 (light green) and ILC 500 (dark green).*

The production cross section of the Higgs boson in charged current ep collisions at the LHeC is about 200 fb. The anticipated peak luminosity of 10^{34} $cm^{-2}s^{-1}$ and a lifetime of about a decade of operation may deliver about an ab^{-1} of data which provides $O(10^5)$ Higgs bosons. The clean final state, the unique distinction of ZZH and WWH production and a well-controlled theory enable per cent level ep measurements of the Higgs boson couplings in the dominant decay channels, mostly complementary to those in pp. The HL-LHC and LHeC prospects have been analysed jointly. They are presented in Figure 1 for the seven most abundant Higgs decay channels, representing 99.8% of the total SM decay width. The substantial improvement of the HL-LHC prospects by the addition of ep is evident. It leads to O(1)% precision for all these couplings, with 3-4% for charm which is likely not accessible at the LHC. These results are comparable to those envisaged for ILC 250 which assumes $2ab^{-1}$ and polarised e^- and e^+ beams [*1710.07621*], albeit less precise than the expectation for ILC 500 (with 4 ab^{-1}) as is also shown in Figure 1. A detailed Higgs prospect analysis is available in [*1905.03764*].

An Energy Recovery Linac for the LHC

The LHeC provides an intense, high-energy, low emittance electron beam to collide with the LHC. It represents a most prominent high-energy application of energy recovery linacs. ERL technology is increasingly recognised as an important means for the development of particle physics with the potential also to revolutionise the application of accelerators in many industrial and other research areas and to stimulate superconducting RF technology progress. By keeping the power low and dumping at the low injection energy, ERLs are environmentally friendly machines. In the case of the LHeC, the wall-plug power could be limited to 100 MW, while without ERL it required in excess of a GW and would be seen as unrealistic. The ERL beam configuration, apart from the interaction region (IR), is located outside the LHC tunnel, which minimises any interference with the main hadron beam infrastructure. The electron accelerator may thus largely be built independently of the status of operation of the proton machine. LHeC operation is transparent to the LHC collider experiments owing to a still low lepton bunch charge and resulting small beam-beam tune shift experienced by the protons. The LHeC is thus designed to run simultaneously with hh collisions, with a dedicated final operation of a few years. The original and the updated CDR present the accelerator design in detail, the main parameters, design considerations, lattice, magnets, RF, cryogenics, interaction region etc. Given the dominance of the linac RF cost, the LHeC is designed as a three-turn racetrack configuration, with oppositely positioned linacs operating at 802 MHz frequency, suitable for LHC and CERN, and a default 20mA electron current.

Steps Towards its Realisation – Technology, Cost and IP

The basic LHeC configuration and parameters have been adopted for PERLE [*1705.08783*], a 500 MeV ERL development facility, which will be built at IJCLab Orsay in an international collaboration with AsTEC Daresbury, BINP Novosibirsk, CERN, Jefferson Lab, Liverpool University and possibly further partners. PERLE will be the first 10 MW power ERL facility and is being designed from the ground up to use fully optimised ERL specific concepts and hardware. PERLE will be instrumental in the development of components and for the accumulation of operation experience for the LHeC, while having further accelerator design goals, some of which are in synergy with FCC-ee. It offers an attractive low energy physics programme owing to the huge beam intensity and quality. PERLE will be a part of the strategic accelerator R&D programme being launched this year, and a TDR is expected for 2022.

LHeC is much cheaper than any of the other energy frontier colliders under consideration. Its energy-cost relationship has been revisited. Maximum energy is required for BSM physics. Too high energy readily becomes too expensive. The electron ERL, for ep/eA collisions in Interaction Point 2 (IP2) at the LHC, has a circumference 1/n of that of the LHC. The new paper considers shrinking the configuration from n=3 to n=4 or possibly 5, which results in a reduction of the cost by about 400 MCHF and of the energy from 60 to 50 GeV. A staging option is discussed, starting with 30 GeV, at a cost below 1 BCHF, and upgrading to about 50 GeV at a total cost of 1.3 BCHF. The realisation of the LHeC requires an addition of about 20% of the whole LHC investment, enabling a novel TeV scale collider to substantially empower the LHC programme.

Currently, the ALICE detector resides in IP2 with a programme extending up to LS4. There are new plans for a compact heavy ion detector developed for IP2. The detector concept [*1902.01211*] is for a tracking detector built of MAPS thin silicon wafer technology. Such a technology has similarly been chosen for the LHeC tracker, which extends over 6 m in beam direction. One may thus tentatively think of unifying both designs into one common detector (Figure 2). For the LHeC detector, this would basically imply enlarging the tracker radius, from 60 cm now to about 1 m, which would enable a reduction in the magnetic field strength from 3.5 to perhaps 2 T or even below. The LHeC ep interaction point is shifted by 25/4 ns away from the nominal pp interaction point to avoid parasitic crossings. Collisions of the hadron beams would then have to be enabled, alternating to electron-hadron collisions, and these would occur 1.8 m before the ep IP. Going beyond the LHeC paper presented here, a comprehensive study needs to be launched of both the details of the detector and its readout, and the beam optics, apertures and interaction region design. This will entail prototyping the nearest, most demanding quadrupole magnet. Resolving the visionary conflict about IP2 has long been desirable and the alignment of the two communities would indeed be beneficial.

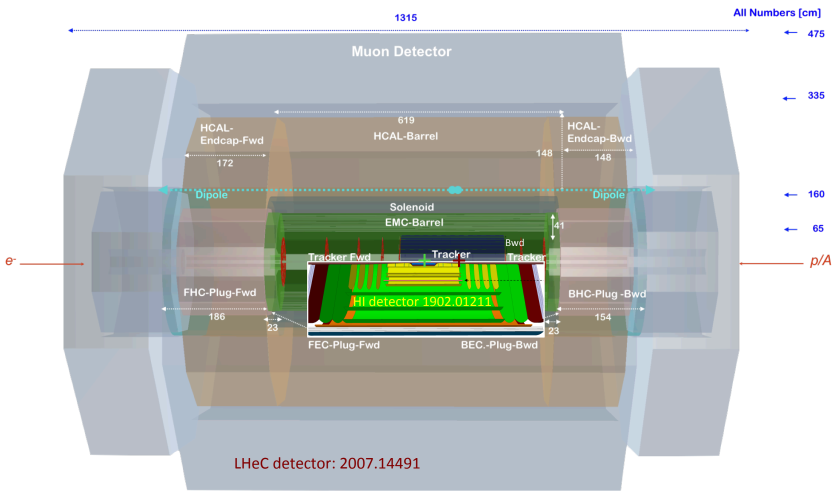


***Figure 2**: Sketch of the LHeC detector with a superimposed novel heavy ion detector (green) proposed for IP2 after LS4, see text.*

The dual eh/hh detector, if feasible, should be suitable for the envisaged low p_T heavy ion programme. As to eA, the LHeC extends the kinematic range in lepton nucleus (eA) scattering by about three orders of magnitude. It therefore is the most powerful electron-ion research facility one could build in the next decade: for clarifying the partonic substructure and dynamics inside nuclei for the first time and elucidating the QCD dynamics underlying the Quark-Gluon-Plasma.

The prospects for discovery and for high precision in the strong and electroweak sectors, the development and application of sustainable accelerator technology, the vision of a dual eh and hh detector using new detector techniques, and the united effort of particle, nuclear and accelerator physicists – all this represents a new horizon for our field, an exciting, realistic medium-term prospect for CERN and for empowering the coming decade of HL-LHC physics, as part of a long term future which the community is jointly about to shape.

Announcements

The next Plenary ECFA meeting will take place at CERN on 19-20 November 2020. Depending on the evolution of the COVID pandemic, this meeting might have to be held via videoconference.

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