ECFA

European Committee for Future Accelerators

ECFA Newsletter #6

Following the Plenary ECFA meeting, 19 and 20 November 2020

https://indico.cern.ch/event/966397/

Winter 2020

It was a great pleasure for ECFA to endorse the membership of the ECFA Early-Career Research Panel at its meeting on 19 November 2020. The panel, made up mainly of PhD students and postdocs, will discuss all aspects that contribute in a broad sense to the future of the research field of particle physics. To capture what is on their minds and to establish a dialogue with ECFA members, a delegation of early-career researchers will be invited to Plenary and Restricted ECFA, while the panel will also advise and inform ECFA through regular reports.

During the Plenary ECFA meeting, we heard about the progress in developing the Accelerator and Detector R&D Roadmaps. The European Strategy for Particle Physics (ESPP) calls on ECFA to develop a detector R&D roadmap to support proposals at European and national levels, and to achieve the ESPP objectives in a timely manner. The ECFA roadmap panel will develop the roadmap taking into consideration the targeted R&D projects required, as well as transformational blue-sky R&D relevant to the ESPP. Open symposia, in March or April 2021, are part of the consultation with the community. In parallel, with a view to stepping up accelerator R&D, the European Laboratory Directors Group (LDG) is developing an accelerator R&D roadmap that takes into account a variety of technologies for further development during this decade. The roadmap will set the course for R&D and technology demonstrators to enable the development of future facilities that support the scientific objectives of the ESPP.

Full exploitation of the scientific possibilities offered by the (HL-)LHC accelerator complex remains the top priority for particle physics in Europe. Accordingly, the upgrades of the LHC and the detectors are well under way. Pending a final decision on a new collider at CERN, options to enhance the scientific potential of the current collider facilities in answering open questions in fundamental physics should not be overlooked. A variety of novel scientific endeavours related to the operation of the (HL-)LHC are being explored by the community and, in addition to the LHC and detector upgrades, some others are already under way. For example, located some 500 metres from the ATLAS interaction region, the FASER experiment is being installed to search for light and weakly interacting particles. These novel possibilities range from using existing beams on target to using these beams in collision with other dedicated laser or particle beams. Important examples are documented in the report of the Physics Beyond Colliders study and the recent update of the LHeC CDR reported in ECFA Newsletter #5. In this context, and on the occasion of the 107th Plenary ECFA meeting, a session dedicated to a Gamma Factory at the LHC was organised, a report of which you will find in this newsletter. The inclusive portfolio for full exploitation of the (HL)-LHC accelerator complex captures the potential for a fascinating research programme for the next two decades.

The global ambition for the next-generation accelerator beyond the HL-LHC is an electron–positron Higgs factory, which could include an electroweak and top-quark factory. Pending the outcome of the technical and financial feasibility study on a future FCC-like hadron collider at CERN, the community has not yet reached a conclusion on the type of Higgs factory that will be given priority. In this newsletter, you will find status reports on the International Linear Collider (ILC) in Japan and the Future Circular Collider (FCC) at CERN. It goes without saying, and it is within ECFA's mandate to explore, that duplication of similar accelerators should be avoided and international cooperation to create these facilities should be encouraged if it is an essential and efficient way to achieve the goal. In several countries, action is being taken to address this, for example by establishing a national collaboration forum for researchers at future Higgs factories and/or future colliders. ECFA recognises the need for the experimental and theoretical communities involved in physics studies, experiment designs and detector technologies for future Higgs factories to come together. ECFA will support a series of thematic workshops starting in 2021 to discuss challenges and share expertise, and to respond coherently to this ESPP priority. An international advisory committee will be formed shortly to further identify synergies in both detector R&D and physics-analysis methods and to make efforts applicable or transferable across e^+e^- Higgs factories and potentially beyond. Concrete collaborative research programmes should emerge to pursue these synergies. In this regard, coordination of R&D activities is crucial to maximise scientific results and to make the most efficient use of resources. With the strategy discussions behind us, we now need to focus on getting things done together.

The ESPP rightly encourages the particle physics community to further strengthen the unique ecosystem of research centres in Europe. The success of our field is based on a strong European organisational model that revolves around close collaboration between CERN and the national institutes, laboratories and universities. In support of this view, it is important for the community to hear regularly about the status and plans of major ECFA-related laboratories. A close relationship between the ECFA community and the management of major European laboratories is essential for the long-range planning of particle physics in Europe. To this end, ECFA has revised its structure to establish a close relationship with all major laboratories represented in the LDG. Frequent reports from the laboratories represented in the LDG will be scheduled on the occasion of Plenary ECFA meetings and, in addition, LDG members will be invited to participate in dedicated Restricted ECFA meetings with an agenda of mutual interest for ECFA and the LDG.

The election of Professor Karl Jakobs from the University of Freiburg as the next chair of ECFA, to serve a term from 2021 to 2023, was endorsed at the Plenary ECFA meeting. We wish him and ECFA all the best!

Our final words are words of gratitude to all the wonderful colleagues in the CERN Council units. In particular, we worked side by side with Yasemin Altinbilek, Anca Patru and Vedrana Zorica in order to get things done, and everything we write on behalf of ECFA would look different without Rosie Arscott, John Pym, Michael Stott and Sarah Waller. Sincere thanks!

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

Reports from laboratories in Europe

Reports from some of the major laboratories in Europe, namely CERN, DESY and LNF (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.

CERN – presented by Eckhard Elsen (CERN Director for Research and Computing)

During the spring 2020 safe mode required by the COVID-19 pandemic, only a few hundred people were present on site at CERN. As lockdowns eased, CERN gradually brought back most of the workforce and, by October 2020, some 6000 people were entering CERN daily. Measures had been put in place at CERN that allowed progress to continue, such as on Long Shutdown 2 (LS2) activities at both the accelerators and the experiments, while maintaining a safe working distance. Specific hygiene measures were developed for each work station, and personal protective equipment had to be worn accordingly. Since the end of October, with the resurgence of the pandemic in the Geneva region, CERN has been encouraging teleworking to reduce personnel on site to 4000.

Nonetheless, progress continues to be impressive. The LHC consolidation and injector upgrade is proceeding according to schedule. The cool-down of the LHC magnets has started. The 11 T Nb_3Sn dipoles slated to replace the existing NbTi dipoles in the LHC have to undergo further testing, as the current drawn is seen to oscillate after a thermal cycle. This thermo-mechanical instability could be traced to the end of the long coil. It has therefore been decided not to install these high-field magnets during LS2. Possible background limitations in heavy-ion runs can be mitigated using crystal collimation and other means.

The experiments tackle LS2 duties best when their experts are on site. ALICE has lowered its well-tested TPC featuring GEM readout into the magnet, and other detectors will follow suit. CMS is also fortunate to have a core expert team available. The ATLAS shutdown is also proceeding well for most components, but the subdetectors for the second New Small Wheel are affected by uncertainties in supplies of sTGC and Micromegas from remote institutes. LHCb is worst hit by the unavailability of experts from remote sites, meaning that the integration schedule of the components is quite uncertain.

The LS2 schedule has been confirmed. The LHC will restart in February 2022 with the goal of having both New Small Wheels for ATLAS in place. Run 3 is then expected to proceed smoothly without major interruptions to essentially double the integrated luminosity of Run 2. This schedule will be re-examined on 15 March 2021.

The ESPP recommendations are being implemented. The Physics Beyond Colliders programme has seen the initial steps taken in the SPS programme. And the Future Circular Collider collaboration held the kick-off meeting for its Innovation Study (FCCIS) in mid-November.

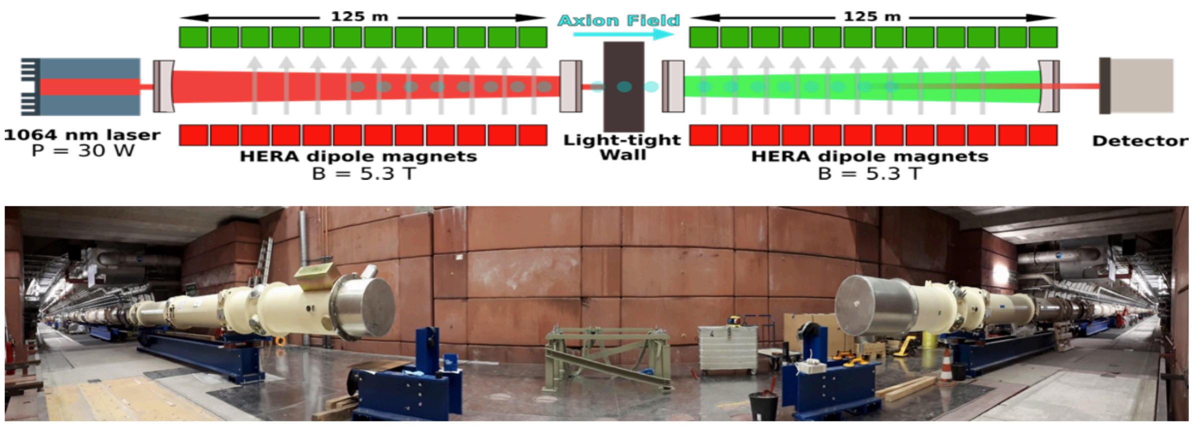
DESY – presented by Joachim Mnich (DESY Research Director)

DESY is coping well with the effects of the COVID-19 pandemic, with most personnel working from home but the user facilities continuing operations.

Work towards the HL-LHC detector contributions is progressing well. Most R&D for the ATLAS and CMS tracker endcaps is finished, and prototyping and procurement are well under way. The lab is also maintaining its level of support for the Belle II experiment, under difficult circumstances because of the pandemic. DESY is again playing a central role in the ongoing preparations for the new pixel-vertex detector PXD 2022.

The programme of on-site experiments at DESY is picking up speed. The ALPS-II experiment has reached a major milestone with the installation of the last of 24 straightened (ex-HERA) dipoles in the HERA tunnel around the location of the former H1 experiment (see picture below). Data taking is due to start in 2021. The axion search experiments BabyIAXO and MADMAX have slightly longer timelines, with data taking for the almost-funded BabyIAXO expected in 2025. In the case of MADMAX, the plan is to go for an intermediate solution – iMADMAX – first, which could start up in 2026.

A conceptual design report is being prepared for the proposed LUXE experiment, which would test non-perturbative QED at the European XFEL, and its collaboration is being further built up.



A schematic view of the ALPS-II layout with its 24 dipole magnets (top), and a recent view of the HERA tunnel, with 12 magnets installed on either side of the future central region of the experiment, seen through a fisheye lens.

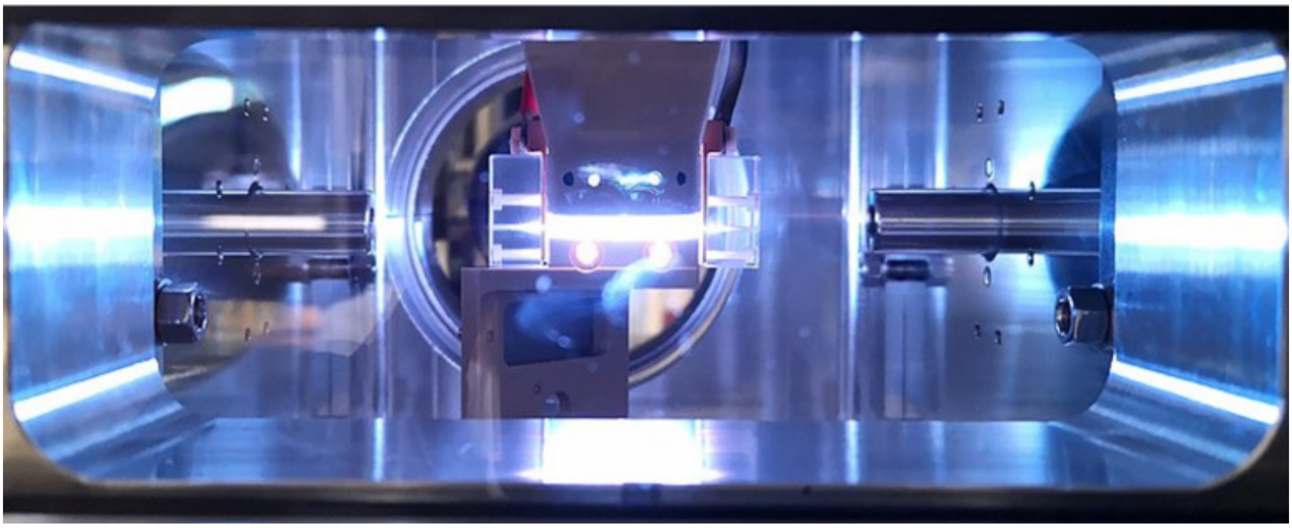
National Laboratory of Frascati – presented by Fabio Bossi (LNF Director)

Despite personnel's restricted access owing to the COVID-19 pandemic, operations at LNF of the two main accelerator facilities ensured that experimental activity could continue.

The DAFNE Linac/BTF delivered beam to the dark photon experiment PADME for the first calibration run in June-July and for physics data taking in September-November [1]. The goal of 5×10^{12} POT events on tape was achieved on time. DAFNE is now starting preparations for the one-year-long run in collision mode for the exotic-atoms experiment SIDDHARTA.

The first demonstration of plasma acceleration in the SPARC_LAB complex was achieved in February 2020 and repeated in July-August. A complete characterisation of the accelerated beam was performed in this second experiment. Although the accelerating gradient was "only" 230 MeV/m, the observed energy spread of the witness was as low as 0.12%, a result that opens up full exploitation of this beam to drive a test FEL experiment at SPARC_LAB. [2].

[1] http://w3.lnf.infn.it/padme-back-hunting/?lang=en
[2] http://w3.lnf.infn.it/first-electrons-accelerated-with-plasma-at-sparc_lab/?lang=en



Discharge capillary used in the SPARC_LAB interaction chamber during the plasma acceleration experiment.

Scheduled mid-term reports from member countries

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

Bulgaria – presented by Plamen Iaydjiev (Institute for Nuclear Research and Nuclear Energy, INRNE)

The research centres for particle and nuclear physics in Bulgaria are the Institute for Nuclear Research and Nuclear Energy (INRNE), Sofia University "St. Kliment Ohridski" (SU) and Plovdiv University (PU). Human resources in fields relevant to RECFA add up to 95 people, 13 of whom are PhD students. In 2020, Bulgaria had about 80 CERN users and 18 staff members, and the total number of Bulgarians involved in CERN activities was 120. Domestic funding for 2020 was 442 kCHF. Bulgaria's membership contribution to CERN constituted around 0.3% of the Member States' total contributions. The industrial return of about 50% of the membership contribution is perceived as well balanced. Since the previous RECFA meeting, progress has been made in the Ministry of Education and Science programme to stimulate PhD students and postdocs; participation in CTA began; a Bulgarian National Roadmap for Research Infrastructure for CERN experiments was developed; and the theory community moved towards more phenomenologically oriented research, primarily driven by a younger generation of theoreticians at INRNE. There is now activity in CTA, Quasar and SU-BAS Consortium for CERN experiments, and research continues in PADME, MICE, SHiP and ESSνSB.

Sweden – presented by David Milstead (University of Stockholm)

Sweden's mid-term report showed a diverse programme of activities. The major CERN-based activities are LHC experiments (ATLAS and ALICE) and ISOLDE. While funding and human resources are at acceptable levels, there is an issue with basic infrastructure funding not being matched with support for infrastructure exploitation and operation. This is relevant for HL-LHC running but is also a general observation for large infrastructure users. This has been the topic of discussions between researchers and the Swedish Research Council, which recently published a report [1] on the funding of accelerator-based infrastructures in particle and nuclear physics. Related to CERN activities, Big Science Sweden (from Sweden's Industrial Liaison Office [2]) is working well on industrial collaboration and tendering. While the core of Swedish particle physics research is focused on the LHC, there are also a number of other activities, including the LDMX, NNBAR and ESSnuSB experiments. In keeping with the ESPP, the community is also starting discussions regarding its involvement in and goals for the next major collider facility. The mid-term report followed up on a number of issues raised at the 2016 RECFA country visit to Sweden. There is a broad accelerator science programme at Swedish institutions and the Max IV laboratory, but a funded coordination effort is still lacking. Similarly, despite Sweden's leading efforts in grid computing, there are shortfalls in funding, particularly with regards to ARC software, and much is being done on a best-effort level. The community is very active in outreach activities but there is no dedicated funding line for, for instance, IPPOG subscriptions.

[1] https://www.vr.se/english/analysis/reports/our-reports/2020-06-12-accelerator-based-infrastructures-in-the-fields-of-particle-and-nuclear-physics.html
[2] https://www.bigsciencesweden.se/

Status of the International Linear Collider (ILC)

by Steinar Stapnes (CERN)

ILC and its key technologies

The ILC250 is a 250 GeV centre-of-mass energy (extendable up to 1 TeV) linear e^+e^- collider, based on 1.3 GHz superconducting RF (SCRF) cavities. The SCRF technology is mature, with a broad industrial base throughout the world, and is in use at a number of free-electron-laser facilities that are in operation (European XFEL at DESY), under construction (LCLS-II at SLAC) or in preparation (SHINE in Shanghai) in the three regions that have contributed to the ILC technology. The second key technology for the ILC is nanobeams, from damping rings to the beam delivery and final focus systems, drawing on experiences from light-sources, FELs and dedicated test facilities, such as the Accelerator Test Facility 2 (ATF2) at KEK. The accelerator baseline parameters, including cost and power estimates, are well documented[1]. The main systems and layout of the 250 GeV ILC are shown in Figure 1.

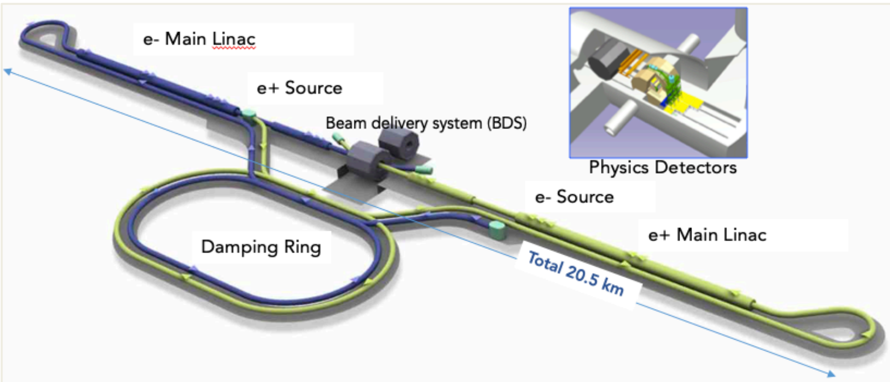


Figure 1: The ILC layout at 250 GeV

Beyond the longer-term ILC luminosity and energy increases that were already planned, in recent years new surface treatments during the cavity preparation process aimed at increasing gradients and/or Q values have been developed, such as that known as nitrogen infusion, and offer new possibilities for initial cost reductions and/or luminosity improvements.

The candidate site in the Kitakami region in northern Japan, close to the cities of Sendai and Morioka, offers a large, uniform granite formation, with no active seismic faults, that is well suited for tunnelling. Local preparations have been going on for several years, but have been further strengthened by the fact that local governments and universities in the Tohoku area established the Tohoku ILC Project Development Center over the summer to address issues that should be handled by the region regarding the construction of research facilities and environmental improvement around the ILC candidate site. Another ongoing important activity is the geological surveys (boring, electromagnetic and seismic) of the underground areas. The National Diet (Japanese Parliament) passed a series of bills this summer related to the recovery efforts after the Great East Japan Earthquake in 2011 that extend those efforts to 2031 and name the ILC's implementation in the region in the context of those efforts.

[1] https://arxiv.org/abs/1903.01629

ILC timeline and current international organisation

In recent years, worldwide linear collider activities have been organised in a Linear Collider Collaboration (LCC) under the auspices of the Linear Collider Board (LCB), set up by ICFA. During the ICFA/LCB meeting in February 2020, ICFA asked the LCB to propose a way to move into a four-year preparatory phase (ILC "Pre-lab") for the ILC. A dedicated International Development Team (IDT) was suggested. In a meeting in August 2020, ICFA set up the ILC IDT and appointed the members of the Executive Board, with a view to establishing the ILC Pre-lab within ~1.5 years.

Figure 2: The ILC IDT, with Executive Board and Working Groups

The mandate of the IDT is to:

1. prepare the work and deliverables of the ILC Pre-lab and to work out, with national and regional laboratories, a scenario for their contributions;
2. prepare a proposal for the organisation and governance of the ILC Pre-lab.

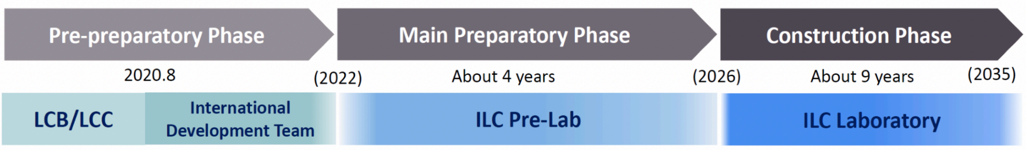


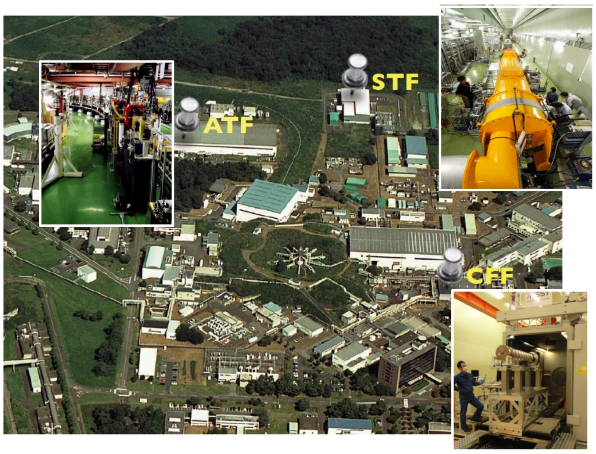
Figure 3: The ILC timeline towards readiness in 2035

Recent progress in Japan

KEK is currently making every effort to start the ILC Pre-lab soon after the IDT completes its mandate, and to realise the ILC together with the Japanese physics community and supporting groups in the political and industrial sectors and the Tohoku region. Major activity has been stepped up in many areas:

- Work towards Japanese funding of the ILC Pre-lab from 2022.
- KEK assuming central roles in Pre-lab planning discussions and leadership in many aspects of the technical work followed up in the IDT Working Groups (in particular for the various accelerator systems, civil engineering and infrastructure); and KEK hosting the IDT.

- Related to the point above, many collaborative projects with partners across the world on technical developments are ongoing or being set up, and associated agreements are being concluded.
- Work with the Tohoku ILC Project Development Center for site preparation, as explained above.



ATF: Studies of nano-size beams
STF: Assemble and operate SC cavities
CFF: Manufacture SC cavities

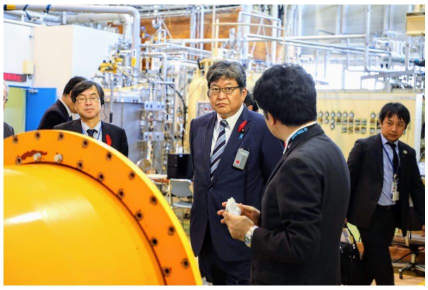


Figure 4: Key facilities at KEK (left), the Minister of Education, Culture, Sports, Science and Technology, Kōichi Hagiuda, visiting KEK (right) (Image: KEK)

Activities have also been stepped up vis-à-vis the wider Japanese physics and general community. In October 2020, the Japan High-Energy Physics Committee (HEPC), which represents the Japanese high-energy physics community (Japan Association of High-Energy Physics – JAHEP), established the ILC Steering Panel to accelerate community-wide efforts to realise the ILC.

Two additional structures are important for rallying broad political and industrial support for the implementation of the ILC in Japan: the Federation of Diet Members for the ILC, with 150 members, and the Advanced Accelerator Association, involving 102 industries.

Recent progress in the Americas

The Americas Workshop on Linear Colliders in October 2020 highlighted the interest in and work on the ILC in the US and Canada. Presentations in the Monday and Thursday plenary sessions (from the US, Canada and Latin America) summarised the status and intentions across the region[1].

Support and planning in the US range from the political level to the laboratories and community. US Deputy Secretary of State Stephen Biegun sent a letter to Japanese Foreign Minister Toshimitsu Motegi in February 2020: "It is necessary to take decisive action to ensure that Japan and the United States continue to be at the forefront in particle physics, and I strongly support the progress of the International Linear Collider Program" (article in the Yomiuri newspaper on 13 May 2020). Similar statements of support were made in the workshop by the State Department, DOE and NSF.

[1] https://agenda.linearcollider.org/event/8622/timetable/

Detailed planning for US Pre-lab interests and capabilities is under way. Laboratory overviews were presented during the workshop and have been followed up in DOE/KEK/US labs meetings since. The contributions identified are currently being transformed into a schedule of possible US deliverables for the Pre-lab period. The discussion of ILC participation and exploitation of its scientific potential is also part of the ongoing Snowmass process.

Recent progress in Europe

Europe has a very strong scientific, technological and industrial basis for making significant contributions to the construction – and Pre-lab activities – of virtually any part of the ILC accelerator. The key activities in Europe that are highly relevant for the ILC are European participation in the ILC Global Design Effort and LCC, the European XFEL project, the ESS superconducting linac, European participation in ATF2, the E-JADE Marie Curie project, and the CLIC study. Recent SCRF work also includes studies and construction of modules for PIP-II and the HL-LHC.

In Europe, the planning process addresses two levels of identifiable Pre-lab contributions:

- R&D interests and capabilities, linked to "local" strategic interests (scientific and technical collaborations). In many cases, the resources for such collaborations exist.
- Identification and preparation of ILC deliverables – a major example is a European SCRF cryomodule production line, in addition to other individual accelerator items (qualifying and preparing to deliver specific parts). Most of this work requires additional resources, to be obtained either by linking them to the successful start of the Pre-lab or promoting them as valuable technical development projects in their own right.

In Europe, there are also several new activities linked to the ILC IDT efforts. European participation in IDT Working Groups has systematically increased so that the European community can participate more efficiently in the Pre-lab planning. A series of European monthly information meetings[2] has begun. The SCRF capabilities in Europe (laboratories and industry) are being consolidated into a possible model for ILC SCRF contributions and, ultimately, cryomodule production. Similarly, groups are considering contributions to the ATF2 and nanobeam studies, positron productions, cryogenics and more.

	Germany DESY	France CEA Saclay	France LAL	Italy INFN Milan	Poland IFJ PAN	Poland WUT	Poland NCBJ	Russia BINP	Spain CIEMAT
Linac									
Cryomodules	✓	✓		✓					
SCRF Cavities	✓			✓					
Power Couplers	✓		✓						
HOM Couplers							✓		
Frequency Tuners	✓								
Cold Vacuum	✓							✓	
Cavity String Assembly	✓	✓							
SC Magnets	✓				✓				✓
Infrastructure									
AMTF	✓				✓	✓		✓	
Cryogenics	✓								
Sites & Buildings									
AMTF hall	✓								

Table 2: Responsibility matrix for cryomodule production and testing for the European XFEL.

Figure 5: Cryomodule production responsibilities for the European XFEL. Additional groups and more recent projects (as mentioned above) have increased capabilities (adding, for example, STFC/Daresbury, Uppsala, CERN and others to the list of potential partners).

National contact people and communities are actively planning for the next five years (IDT and Pre-lab period) and beyond for the ILC. Some recent examples are the UK linear collider community planning meeting[3] on the ILC in September. A Spanish consortium consisting of

[2] https://agenda.linearcollider.org/category/255/
[3] https://indico.cern.ch/event/943948/

CIEMAT/IFIC/ALBA and ESS-Bilbao, together with the INDUCIENCIA/INEUSTAR industrial networks, are exploring potential contributions to ILC magnets for the main linac and damping rings and to the beam dump system of the ILC.

CERN, following up on ESPP statements about the importance of a Higgs factory and European interest in the ILC, has concluded an agreement with KEK for collaboration in the IDT. One of the key aspects is that CERN will facilitate European participation in the work of and the common fund for the IDT. Ongoing or potential collaborative work has been outlined for the accelerator's beam delivery system and ATF2, high-gradient acceleration and high-efficiency klystrons, detector, physics and software, cryogenics systems, beam dumps, SCRF module components and technologies, civil engineering studies, positron production and beam dynamics. These are areas where CERN has already provided technical advice as part of the LCC, or has matching activities where collaboration is or could be beneficial.

Next months and year for the IDT

Based on the efforts above, an immediate goal is to establish a preliminary list of Pre-lab tasks and deliverables, and of national/regional laboratories that might be interested in contributing to those. This will include bottom-up estimates of resource needs for the regional activities and the central Pre-lab office. A preliminary proposal for the Pre-lab organisation and governance is being prepared. These are all key elements needed for the Pre-lab Japanese funding request preparation by KEK in 2021 to obtain funding in 2022. Similar planning requirements are expected for other countries.

The next linear collider workshop (in the LCWS series, i.e. both CLIC and ILC) in spring 2021 in Europe (a virtual event) will include a wide-ranging discussion/sessions on ILC physics opportunities. It will be followed by a dedicated workshop in autumn 2021 to discuss ideas for experiments at the ILC, at the collision point and beyond, covering broad physics spectra and associated R&D activities, considering all the beam capabilities of the facility.

Status of the Future Circular Collider (FCC)

by Michael Benedikt and Frank Zimmermann (CERN)

At the end of 2018 the first phase of the Future Circular Collider (FCC) study was successfully completed with a four-volume Conceptual Design Report (CDR) [1-4]. The 2020 Update of the European Strategy [5] rings in the new "feasibility phase" of the FCC design study, and sets the high-level goals for the end of 2025:

1. proof of feasibility of infrastructure and tunnel;
2. a financial plan for the construction and operation phases;
3. a concept for the governance structure;
4. the demonstration of the collider's feasibility, further R&D progress and key technology proof of principles;
5. an approach to energy consumption and environmental aspects;
6. an advanced CDR ("CDR++") for the entire integrated project;
7. a concrete plan for the international collaboration to build and operate the collider, with distributed lead roles.

The results of the FCC "feasibility phase" will serve as an important input to the next European Strategy Update, scheduled for 2026-27.

Specifically, during the feasibility phase, for 2025-26 the FCC study will work out a single scenario, comprising the FCC-ee as stage 1 and the FCC-hh as stage 2. The sequential nature of this programme needs to be taken into account in the level of detail in accelerator studies and R&D for the FCC-ee and the FCC-hh. A number of integrated project milestones have been defined. Assuming support by the next European Strategy Update in 2026-27 and possible project approval in 2028, the FCC tunnel construction could begin around 2030. The first e^+e^- collisions in the FCC-ee are then foreseen by 2040, FCC-hh high-field magnet series production could be launched in 2045 or later, and the earliest possible starting date for the FCC-hh machine installation may be envisaged around 2050 or 2055.

To keep to the FCC technical roadmap, shown in Fig. 1, preparatory civil-engineering activities planned for the period 2020-2030 are of the utmost importance. To accomplish the proof-of-principle feasibility demonstration, high-risk site investigations are scheduled for the years 2022-23.

The CDR++ for the FCC-ee should present a complete collider design with full beam dynamics simulations, a complete injector design with proof of principle e^+ production yield and capture demonstration, a concept design for all scalable technical systems, R&D on non-scalable or critical systems including key prototyping, a technical infrastructure design and infrastructure cost estimates obtained with the help of external consultants, and further cost estimates, schedule and concepts for component production and construction. The CDR++ work should also build up appropriate CERN in-house expertise for FCC-ee construction and operation. For the FCC-hh, the high-field magnet development is the main activity, with appropriate milestones for 2025-26. The FCC-hh development also needs to remain consistent with the FCC-ee design with regard to layout and implementation, e.g. for the injection lines. The insertions for the FCC-hh collimation and beam dump will be optimised for length, efficiency, etc., and ongoing R&D (e.g. on beam transfer, vacuum system design and coating) will be completed. Requirements on FCC-hh infrastructure and civil engineering will need to be fully developed.

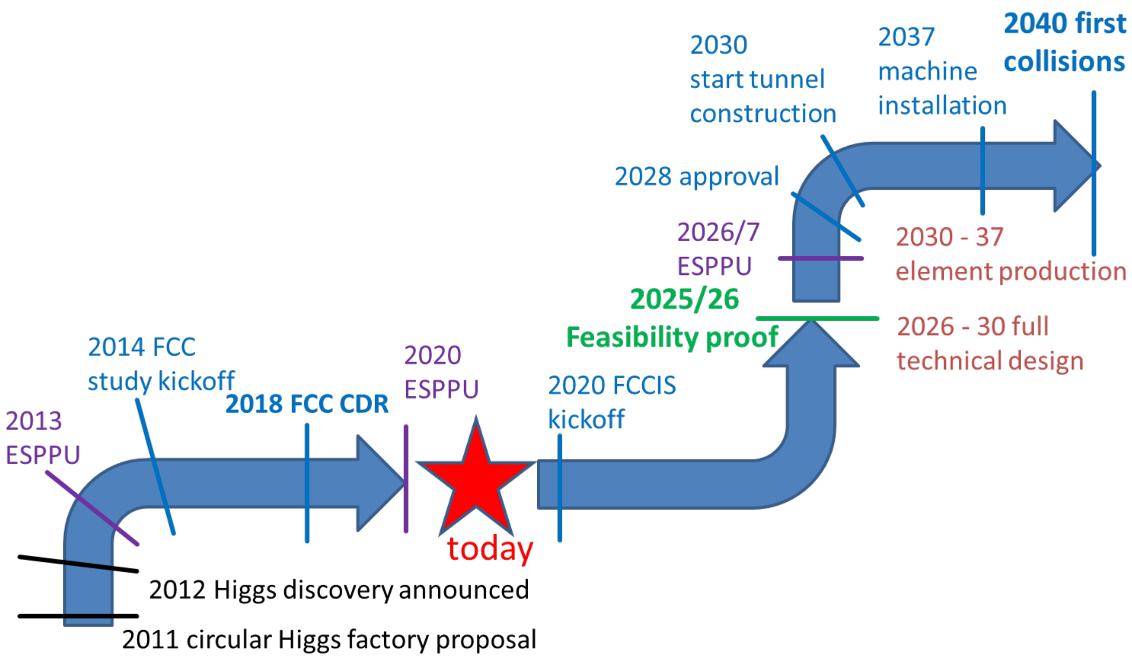


Figure 1: The FCC technical roadmap from 2011 through to 2040, assuming adequate funding.

The key technology for the FCC-ee is the staged superconducting RF system, consisting of three different types of RF cavities operating at 400 and 800 MHz. A comprehensive targeted R&D programme, supported by the European Union's MSCA EASITrain network [6], addresses the respective optimum cavity shapes, improved cavity production methods, cryomodule optimisation, high-power fundamental and higher-order mode couplers, and highly efficient RF power sources. Multi-cell 400 MHz Nb/Cu cavities, as required for the Higgs factory operation mode, and a full SRF cryomodule shall be available by 2025.

Other hardware developments for 2025 include the mock-up of an arc half-cell, about 25 m long, for optimisation of integration, interfaces between systems, installation and maintenance aspects, etc. The arc cell is a key element of the collider, which will be required over about 80 km of the FCC-ee's circumference. Another important proof-of-principle demonstration is a high-yield positron source target with a DC SC solenoid, or alternatively flux concentrator, complemented by a positron capture linac, which will be tested with beam at the PSI SwissFEL facility, allowing single-shot yield measurements at variable primary beam energy.

Serendipitously, the design electron-beam parameters of the recently approved Electron–Ion Collider (EIC) [7] in the US bear great similarity with those of the FCC-ee. This synergetic coincidence may enable collaborations on numerous topics of mutual interest, and benchmarking of simulations and hardware in actual EIC beam operation, which is expected to start by the end of 2030.

Beyond the challenges in accelerator design, substantial work is foreseen both for the design of future FCC detectors and experiments and for the implementation and civil engineering. The recently launched Horizon 2020 FCC Innovation Study (FCCIS) [8] – Fig. 2 – will not only support the optimisation of the FCC-ee lepton collider, but also advance the construction planning, prepare for environmental evaluation, study the management of excavation materials, catalyse user community building and public engagement, and perform socio-economic impact analyses.

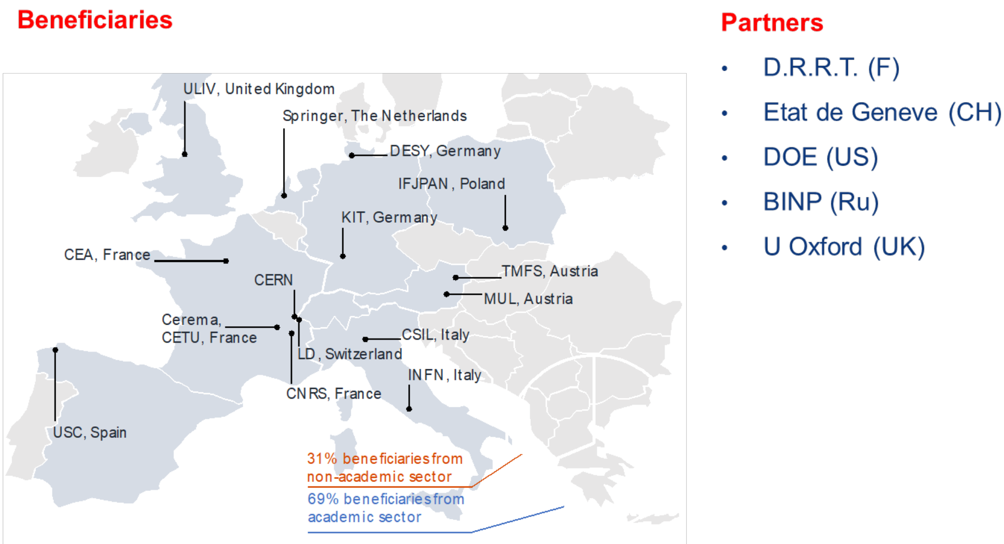


Figure 2: Beneficiaries and partners of the recently approved EU H2020 FCC Innovation Study [10] (2020-24), which will make important contributions to the FCC "Feasibility Phase".

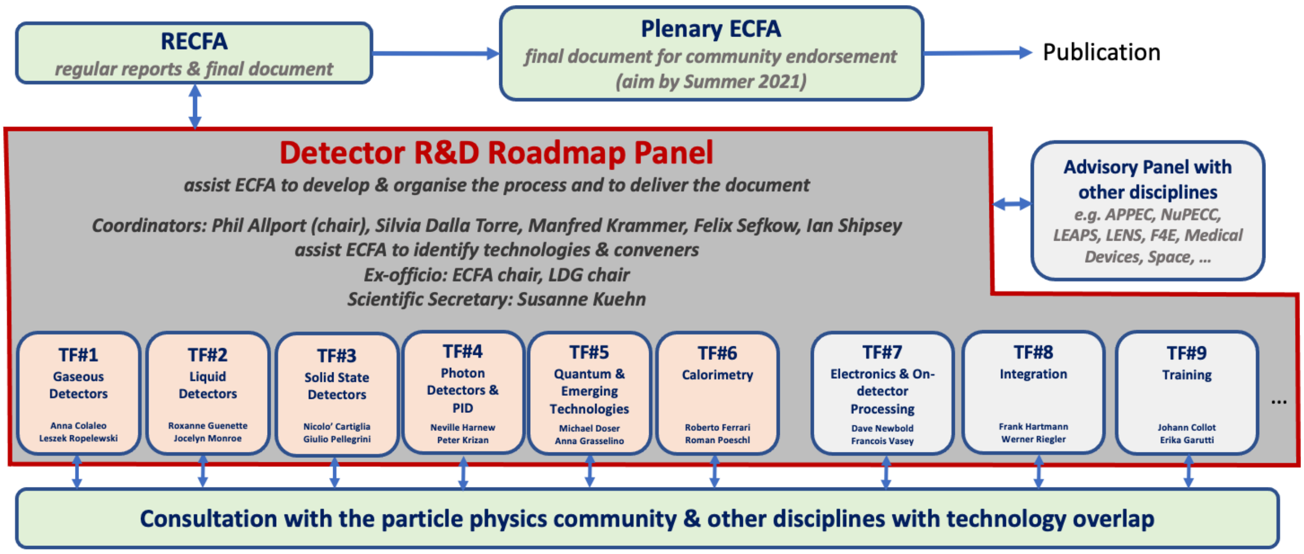
[1] M. Mangano et al., FCC Physics Opportunities – Future Circular Collider Conceptual Design Report Volume 1, EPJ C 79, 6 (2019) 474 [Open Access].
[2] M. Benedikt et al., FCC-ee: The Lepton Collider – Future Circular Collider Conceptual Design Report Volume 2, EPJ ST 228, 261-623 (2019) [Open Access].
[3] M. Benedikt et al., FCC-hh: The Hadron Collider – Future Circular Collider Conceptual Design Report Volume 3, EPJ ST 228, 755-1107 (2019) [Open Access].
[4] F. Zimmermann et al., HE-LHC: The High-Energy Large Hadron Collider – Future Circular Collider Conceptual Design Report Volume 4, EPJ ST 228, 1109–1382 (2019) [Open Access].
[5] European Strategy Group, 2020 Update of the European Strategy for Particle Physics, CERN-ESU-013 (2020).
[6] The European Advanced Superconductivity Innovation and Training (EASITrain) Marie Skłodowska-Curie Action (MSCA) Innovative Training Networks (ITN) receives funding from the European Union's Horizon 2020 Framework Programme under grant agreement no. 764879; https://easitrain.web.cern.ch/ .
[7] Electron–Ion Collider eRHIC Pre-Conceptual Design Report, BNL Report BNL-211943-FORE, July 2019.
[8] The FCC Innovation Study is an INFRADEV Research and Innovation Action project receiving funding from the European Union's Horizon 2020 Framework Programme under grant agreement no. 951754; FCCIS Kickoff Workshop, 9-13 November 2020.

Detector R&D Roadmap

by Susanne Kuehn (CERN) on behalf of the ECFA Detector R&D Roadmap Panel

The European Strategy for Particle Physics (ESPP) sets out scientific recommendations for our field that provide guidance on future research facilities and on concerted efforts to extend our current knowledge. It points out that advances in instrumentation are required through both focused and transformational R&D. The ESPP calls upon ECFA to develop a global detector R&D roadmap to support proposals at the European and national levels. The aim of the roadmap is to guide detector R&D in the near and long term.

A Detector R&D Roadmap Panel will help ECFA to develop the process and to deliver the final roadmap document. An overview of the panel and the organisation of consultations with the community can be found in the chart below.



With the updated ESPP as input, the mandate of the ECFA Detector R&D Roadmap Panel is to focus on the technical aspects of realising the research facilities in a timely fashion, and to provide strategic guidance for detector development in general, in synergy with neighbouring fields and industrial applications. The technological challenges are captured in six technology-oriented task forces (TF1-TF6) and three cross-cutting task forces (TF7-TF9). Each task force will develop a time-ordered R&D requirements roadmap in terms of key capabilities that are not currently achievable.

Input from the community is envisaged in various ways: the two conveners and about four expert members per task force will collect information from the community; proponents of future facilities will be invited to discussions with the panel; and one-day symposia for each task force in March/April 2021 will inform the discussion. An advisory panel comprising other disciplines – to identify synergies and opportunities with adjacent research fields and to draw up a list of national expert contacts provided by ECFA members – will complete the input collection. We look forward to broad participation in the open symposia, which will culminate in a European Detector R&D Roadmap document in summer 2021.

Accelerator R&D Roadmap

by Leonid Rivkin (PSI) on behalf of the Laboratory Directors Group

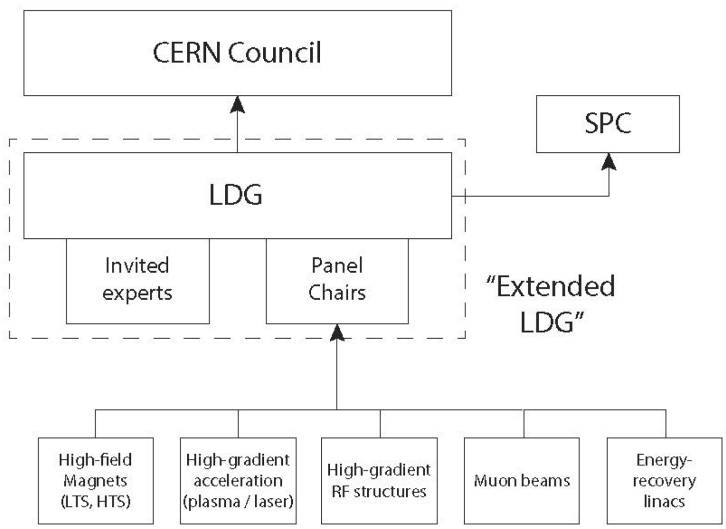
As an outcome of the 2020 ESPP update, the Laboratory Directors Group (LDG) was mandated to establish a prioritised accelerator R&D roadmap for particle physics. The roadmap will map a route towards implementation of the scientific goals of the ESPP, bringing together the capabilities of CERN, large national laboratories and other institutes, to carry out R&D and the construction and operation of demonstrators.

Through its outcomes, the roadmap will inform the next ESPP update. It will:

- provide an agreed structure for a coordinated and intensified programme of particle accelerator R&D, including new technologies, to be coordinated across CERN and national laboratories;
- be based on the goals of the ESPP, and established in its implementation through consultation with the community and, where appropriate, through the work of expert panels;
- take into account, and coordinate with, international activities and work being carried out in related scientific fields, including development of new large-scale facilities;
- specify a series of concrete deliverables, including demonstrators, over the next decade;
- be cognate with corresponding roadmaps in detectors, computing and other developments, with a compatible timeline and deliverables.

The ESPP highlights several key areas where progress in R&D is needed:

- High-field magnets, including use of high-temperature superconductors
- Plasma wakefield and laser high-gradient acceleration
- High-gradient RF structures (superconducting and normal conducting)
- Bright muon beams
- Energy recovery linear accelerators



The process will be steered by the "extended LDG", comprising LDG standing members, the chairs of the expert panels and any other experts invited by the LDG Chair. Panels will be set up in autumn 2020 and work until delivery of the report in September 2021. They will:

- consult widely with the European and international communities, taking into account the capabilities and interests of stakeholders;
- establish synergies with related scientific fields, such as light sources, neutron sources, and nuclear physics and astrophysics facilities;
- propose and recommend ambitious but realistic objectives, work plans and deliverables.

Gamma Factory

by Dmitry Budker (Helmholtz Institute Mainz and UC Berkeley), Yann Dutheil (CERN) and Mieczyslaw Witold Krasny (LPNHE – Sorbonne University Paris and CERN)

The next CERN high-energy frontier projects, such as the FCC-ee or a muon collider, may take a long time to be approved, be built and become operational – in the most optimistic scenario, not before 2045 (FCC-ee) or 2050 (μ-collider).

As soon as the HL-LHC has produced its designed luminosity, a strong need will arise for a novel research programme to fill the gap and re-use – or co-use – the existing CERN facilities, including the LHC, in ways that were not necessarily foreseen when the machines were designed. The Gamma Factory research programme could fulfil such a role while making use of the unique scientific infrastructure at CERN.

The starting point of the Gamma Factory initiative was the identification of the enormous, but largely underappreciated, potential of the existing CERN accelerator infrastructure for conducting novel research at the crossroads of particle, nuclear, atomic, accelerator and applied physics, in addition to forging links with ongoing astrophysics research. Each of these disciplines could profit from the Gamma Factory project through the different avenues discussed below.

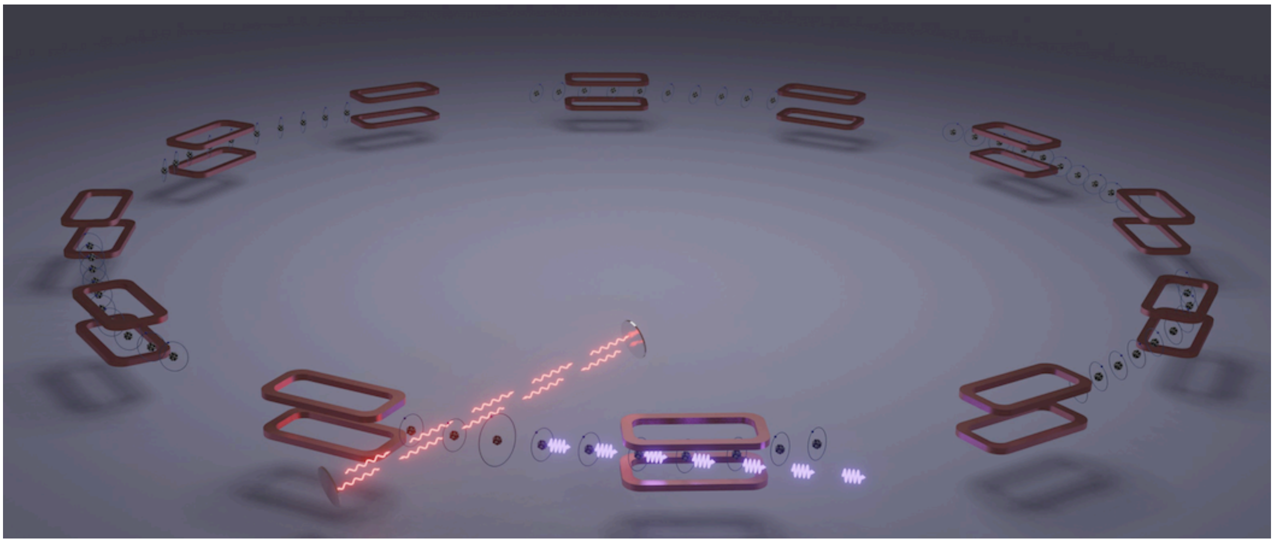
Big trap for highly charged ions – This Gamma Factory project proposes producing and storing highly relativistic beams of partially stripped (highly charged) ions in high-energy storage rings, acting as effective atomic traps. Such a novel trap, moving close to the speed of light, could open up new atomic physics research opportunities through studies of the QED vacuum and electroweak effects affecting small-size atomic systems: hydrogen-, helium-, lithium-like, etc. ions. Thanks to the large relativistic Lorentz-gamma factor of the stored high-Z ions, their atomic degrees of freedom could be resonantly excited, for the first time, with visible laser light, relativistically upshifted in frequency when seen in the frame of the ions.

Electron beam – Atomic beams of hydrogen-like ions can be considered as quasi-independent electron and nuclear beams. Each day of Pb^{81+}–proton collisions would produce, at the interaction point of each of the LHC detectors, an effective ep-collision integrated luminosity comparable to that in the first year of HERA's operation in 1992. Electron–proton collisions could provide an in situ diagnostic of the emittance of partonic beams at the LHC.

Gamma source – The Gamma Factory photon source (see figure below) is based on a novel technology that employs resonant elastic scattering of laser photons on ultra-relativistic partially stripped atoms. The outstanding characteristics of the gamma-ray source are that it is point-like and has unprecedented high intensity, tunable photon energy and high monochromaticity of collimated photon beams.

Novel methods of cooling hadronic beams – Selective photon absorption and random emission naturally open a path to new beam cooling techniques. Analogous to methods of cooling stationary atoms – exploiting internal degrees of freedom and the Doppler effect – it is possible, using the CERN rings, to form hadronic beams of unprecedentedly small longitudinal and transverse emittances within a seconds-long time scale.

Tertiary beams – The Gamma Factory's high-intensity, tunable-energy photon beams open new ways of creating tertiary beams of polarised positrons, muons, neutrinos, pions, neutrons and radioactive ions of unprecedented intensity and quality.



Gamma Factory concept. Laser photons impinge onto ultra-relativistic ions circulating in a storage ring. Resonantly scattered photons of high energy, as seen in the laboratory frame, are emitted in a narrow cone in the direction of the motion of the ions.

Physics highlights

The Gamma Factory tools could be used in exploratory studies in many scientific fields. They could also play an important role in ongoing research in:

- particle physics (studies of the basic symmetries of the universe, dark matter searches, precision QED and EW studies, vacuum birefringence studies, Higgs physics in γγ collision mode, rare muon decays, precision neutrino physics, the search for physics beyond the Standard Model);
- accelerator physics (beam-cooling techniques, low-emittance hadronic beams, plasma wakefield acceleration, high-intensity polarised positron and muon sources, beams of radioactive ions and neutrons, narrow-band and flavour-tagged neutrino beams, spin-dynamics studies);
- nuclear physics (confinement phenomena, nuclear spectroscopy, nuclear photo-physics, fission research, gamma polarimetry, physics of rare radioactive nuclides, interaction of atomic and nuclear degrees of freedom);
- atomic physics (electronic and muonic atoms, pionic and kaonic atoms, strong-field physics, parity violation);
- applied physics (accelerator-driven energy sources, cold and warm fusion, production of medical isotopes and isomers).

Gamma Factory study group

The Gamma Factory initiative was presented in 2015 (https://arxiv.org/abs/1511.07794). In 2017, the Gamma Factory study group, embedded within the Physics Beyond Colliders (PBC) framework, was created by CERN. So far, about 90 physicists from 35 institutions have contributed to the development of this project. The CERN PBC framework has played a crucial role in bringing our accelerator tests, the Proof-of-Principle (PoP) experiment design, software development and physics studies to their present stage. The GF group is open to everyone who wants to contribute to the studies.

Gamma Factory status

The Gamma Factory group has already reached two of its six milestones. Efficient production, acceleration and storage of "atomic beams" have been demonstrated in a series of beam tests with partially stripped xenon and lead ions at the SPS and LHC at CERN. The requisite software tools for the beam lifetime, electron-stripping efficiency, and partially stripped ion beam collimation studies have been developed. Novel software tools, allowing us to simulate collisions of bunches of partially stripped atoms with laser pulses and betatron and synchrotron oscillations of the beam particles, have been created.

We are now working towards reaching the next two milestones. We are studying the physics highlights of the LHC-based GF research programme, with various scientific communities evaluating the proposed GF tools in their respective research. In parallel, following the preparation of the Letter of Intent for the Gamma Factory Proof-of-Principle experiment in the SPS tunnel and its submission in September 2019, we are looking forward to its approval by the SPSC, following which we will be able to install the experiment and test the photon-production scheme.

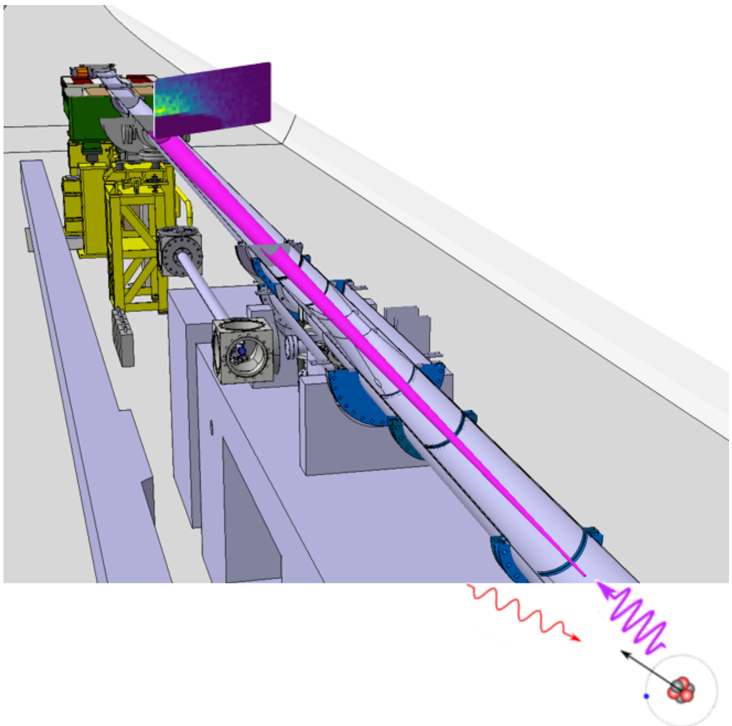
Successful execution of the GF PoP experiment in the SPS tunnel is necessary for the quantitative extrapolation of its results to the LHC and for the precise assessment of the performance figures of the GF programme. Our goal is to reach this milestone prior to the next European Strategy update. This would allow us, if the Gamma Factory project is endorsed by the European Strategy update, to elaborate the Technical Design Report for the LHC-based GF research programme.

Gamma Factory PoP experiment

The goal of the PoP experiment is to study collisions between a laser beam and an ultra-relativistic beam of partially stripped ions (PSI) circulating in the SPS ring. This experiment is the next natural step in the ongoing feasibility studies of the GF initiative for CERN. The outcome of this experiment will validate the capacity of the GF scheme to produce high-intensity gamma-ray beams by colliding laser pulses with PSI bunches stored in the LHC.

The first goals of the proposed experiment are to demonstrate the integration and operation of a laser system at a hadron ring. The experimental procedure will demonstrate stable and controlled excitation of the PSI over long timescales, culminating in the observation of strong and rapid longitudinal beam cooling. The final phase of the PoP programme will investigate the feasibility of atomic physics measurements in the ultra-relativistic regime.

The current PBC Gamma Factory study group can be considered a proto-collaboration. Even if it is already significant in size and includes – in most of the PoP experiment domains – the required expertise, the Gamma Factory group welcomes everybody who would like to contribute to the successful construction and operation of this experiment and the analysis of the resulting data.



The planned interaction region for the PoP experiment at the CERN SPS.

The way forward

Over the last four years the Gamma Factory proposal has developed into a well-defined project involving a large group of physicists. Progress has been impressive. The next steps are clear. The Gamma Factory R&D studies now enter the decisive phase of the Proof-of-Principle experiment and the quantitative evaluation of the physics highlights of its research programme. Continuous support from CERN (the proposed host of the Gamma Factory) will play a pivotal role in the further development of Gamma Factory studies in Europe. We hope that our three presentations to ECFA will contribute to divulging the highlights of the Gamma Factory research programme, help people to evaluate the importance of the present R&D activities, and result in recognition and further support for our project.

European Plasma Research Accelerator with eXcellence In Applications (EuPRAXIA)

by Ralph Assmann (DESY) and Massimo Ferrario (INFN, NLF)

The EU-funded project on a European Plasma Research Accelerator with eXcellence In Applications (EuPRAXIA) has completed its conceptual design phase and is making good progress towards its implementation. Five European governments (with Italy as the lead country) have officially endorsed the EuPRAXIA application for the 2021 ESFRI roadmap of future large research infrastructures in Europe. The application was submitted in early September 2020, was found eligible and has entered the ESFRI review. The EuPRAXIA Consortium has agreed that LNF-INFN at Frascati in Italy will host one of the possibly two construction sites and the international project headquarters. The EuPRAXIA project will combine cutting-edge RF technology from the CLIC linear collider study at CERN and an innovative compact plasma accelerator for delivering state-of-the-art pulses of electrons able to drive positrons, X-rays and FEL light sources. This break-through, first-time facility will serve users from various applied fields while developing a new technology for long-term applications in industry and particle physics. Setting up Europe's most southerly free-electron laser, it will provide opportunities for the young generation and strengthen the scientific and technological basis in the metropolitan area of Rome and the whole south of the EU. Expressions of interest have been submitted from user groups in the fields of structural biology, medicine, materials, archaeology, physics and detectors.

A second, more laser-centric construction site for EuPRAXIA will be selected in 2023; at present, the possible locations are in the Czech Republic, Italy and the UK. EuPRAXIA excellence centres will be set up in the Czech Republic, France, Germany, Hungary, Portugal and the UK and will contribute to the technical design, R&D, prototyping and production. About 20% of the required total construction funds have already been secured and work on the new EuPRAXIA building has started at the construction site at Frascati in Italy. The Preparatory Phase and Technical Design projects are under way. As the first step, a new consortium numbering, at present, 40 members and 10 observers from 15 countries in Europe and Asia, as well as the United States, has been formed. A socio-economic impact study has been conducted and shows an expected return rate of 9.2% for the investment. With its new concepts, published in peer-reviewed journals such as PRL and awarded the Touschek prize by the European Physical Society's Accelerator Group, EuPRAXIA will reinforce international competitiveness, innovation and scientific output in the European research area.

Visualisation of the EuPRAXIA facility at LNF-INFN at Frascati in Italy. The future building will house Europe's most southerly free-electron laser. EuPRAXIA will exploit compact CLIC technology and plasma accelerators for high-impact near-term applications, while developing new technology for industry and particle physics.

The US Snowmass process

by Young-Kee Kim (University of Chicago)

Every few years, the US particle physics community comes together to identify and document a scientific vision for the future of particle physics in the US with our international partners. This year-long community-wide study, called "Snowmass", is named after its original venue and is organised by the Division of Particles and Fields (DPF) of the American Physical Society (APS). The Snowmass report is informative and influential for the Particle Physics Project Prioritization Panel (P5) that follows. The P5 formulates a 10-year execution plan in a 20-year perspective to offer important opportunities for US investment in particle physics, placed in order of priority under various budget scenarios.

The Snowmass process involves intense work and satellite meetings and workshops throughout an academic year, culminating in a ten-day gathering at the end of the process. Snowmass 2021 was launched in April 2020 with 10 frontiers (energy, neutrino, rare processes & precision measurements, cosmic, theory, accelerator, instrumentation, computation, underground facilities, and community engagement) and 80 topical groups. Due to the COVID-19 pandemic, frontier groups and topical groups have been holding virtual meetings and workshops in anticipation of a ten-day-long gathering in July 2021 at the University of Washington campus in Seattle.

From 5 to 9 October 2020, a community-wide planning meeting took place virtually, with about 3000 participants. The primary goal of this meeting was to develop plans or steps to achieve a successful Snowmass 2021 report. On the first day, we heard an inspiring talk about the field, strategies and plans in other regions and in related fields, remarks from funding agencies, and voices from our community. Breakout sessions on the second and third days focused on establishing cross-working-group connections and identifying gaps and areas for further study. The final day's programme included a panel discussion on future global accelerator facilities, each frontier's scientific questions and plans between October 2020 and the Snowmass report, and early career researchers' activities and plans.

While the Division of Particles and Fields takes the lead in organising our community studies, the Snowmass process will not succeed without strong participation from our international colleagues, and without the partnership of other professional groups representing the accelerator, nuclear, astro and gravitational physics communities. The Snowmass wiki (https://snowmass21.org/) is a one-stop shop providing all Snowmass information.

The African Strategy for Fundamental and Applied Physics (ASFAP)

by Fairouz Malek (CNRS-IN2P3)

Considering the scarcity of resources, it is important for the world community of scientists, engineers, technicians, funding agencies and policy-makers to come together and define a concerted strategy. Such efforts have been or are currently being conducted in other regions. The process of defining an African strategy demonstrates the true spirit of international cooperation that forms the common denominator of today's culture of our scientific activities, focused on defining priorities for domestic and interregional projects to be supported. However, African initiatives promoted by African countries with their own resources – in some cases in partnership with international institutes – are numerous. In our field, these include, to name just a few, the East Africa Institute for Fundamental Research (EAIFR), the Egyptian Network of High Energy Physics, the similar RUPHE network in Morocco and the excellent infrastructure of the H.E.S.S. experiment in Namibia, not to mention the prestigious universities in South Africa and their high-level research laboratories, such as iThemba Labs, the Square Kilometre Array (SKA), which is a global radio-astronomy project with a major site in Africa, and the regional X-TechLab project in Benin. This is not an exhaustive list.

We feel that Africans developing their own strategy for science and technology will have major benefits, allowing international partners interested in capacity development and retention in Africa to integrate input from Africans themselves, rather than defaulting to their own views of how they may want to "help" Africans. Furthermore, we hope that the African strategy will help to inform African and Pan-African policy-makers.

In pursuing this vision, the African scientific communities emphasise the importance of building synergy between fundamental physics and practical applications, which is crucial for solid education as well as innovation in Africa. Investments in education, technical competencies and training and in science, technology, research and innovation remain critical.

The structural organisation of ASFAP (https://africanphysicsstrategy.org/) includes a Steering Committee (STC) made up of professional scientists who are still active in their fields and well connected to the international community and an International Advisory Committee that will advise the STC. Working groups related to the various fields of fundamental and applied physics have been set up, as well as some special working groups focused on more general topics, such as community engagement, education, early careers, etc.

The African Physical Society (AfPS), a pan-African society, will serve as the host of the strategy development activities. ASFAP was launched on 18 November 2020 and already has a strategy timeline in place, culminating in the delivery of the final report to African policy-makers and funding agencies by the end of 2022.

ASFAP African Strategy for Fundamental and Applied Physics

The Muon Collider collaboration

by Daniel Schulte (CERN)

A muon collider offers a unique road to high-energy colliders and has the potential to combine discovery reach with precision physics. This year, the update of the European Strategy for Particle Physics recommended R&D on muon beams as a high priority and urged the Laboratory Directors Group (LDG), which represents the large European laboratories, to include it in the Accelerator R&D Roadmap. The LDG launched an international muon collider collaboration and appointed Daniel Schulte as interim study leader, supported by Nadia Pastrone and Lenny Rivkin. CERN will initially host this study and has included a budget of 2 MCHF per year in its Medium-Term Plan. A memorandum of understanding for the collaboration is in preparation.

In the past, the possibility of a muon collider has been studied mainly in the US. In Europe, important contributions were the MICE experiment, which recently published its results on the cooling of muon beams in *Nature* (https://doi.org/10.1038/s41586-020-1958-9), and EMMA in the UK. The muon collider study now offers a new opportunity for particle physics. It aims to ascertain, in time for the next European Strategy update, whether the substantial investment into a full CDR and a demonstrator would be scientifically justified. To this end, it will provide a baseline concept and well supported performance expectations and assess the associated key risks, as well as cost and power consumption drivers. It will also identify an R&D path to demonstrate the feasibility of the collider.

The study will focus on two energy ranges. The first is around 3 TeV and largely exceeds that of a Higgs factory. The second is in the 10+ TeV range and would require more advanced technologies. In addition, the synergy with other options, such as neutrino or Higgs factories, will be explored.

Muon collider design efforts have started by bringing US, Asian and European experts together to review the existing design and to identify and address issues. A number of letters of interest have been submitted to the ongoing strategy process in the US and more complete papers will follow next year.

The study has formulated tentative luminosity goals (1 ab^{-1}, 10 ab^{-1} and 20 ab^{-1} for 3, 10 and 14 TeV, respectively) and defined tentative performance specifications for the detector in the form of a DELPHES card. They are based on the FCC-hh and CLIC detector concepts, include masking to suppress the muon background and assume that the impact of the remaining beam-induced background can be mitigated. The DELPHES card is serving as the basis for the ongoing physics potential studies and defines the target for the detector design and beam-induced background mitigation studies, which are also being actively pursued. Similarly, accelerator experts from various laboratories have also started to work on muon collider design. If you want to join in, you can subscribe to the mailing lists muoncollider_detector_physics@cern.ch and muoncollider_facility@cern.ch. More information will appear on the collaboration page (muoncollider.web.cern.ch) in due course.

Storage Rings for the Search for Charged-Particle Electric Dipole Moments (EDM)

by Christian Carli (CERN), Paolo Lenisa (Univ. of Ferrara and INFN) and Jörg Pretz (FZ-Jülich)

The JEDI (Jülich Electric Dipole moment Investigations) and CPEDM (Charged-Particle EDM) collaborations propose a storage ring to search for electric dipole moments of charged particles with unprecedented sensitivity. This requires the design of a new type of accelerator, an all-electric storage ring capable of simultaneously maintaining clockwise (CW) and counter-clockwise (CCW) polarised beams – a prime task for the accelerator community. The EDM observable is embedded in the time development of the beam polarisation, a quantity studied in many nuclear/hadron physics experiments. The scientific case rests upon non-electroweak CP-symmetry violation and the related strong CP problem; additional CP violation will elucidate the matter-antimatter asymmetry puzzle of the universe, which falls into the realm of particle and astroparticle physics. Oscillating EDMs are an additional subject of study to search for axion/ALP dark matter, one further outstanding question of contemporary subatomic science.

Various challenges need to be mastered, e.g. storage and spin coherence time of the beams, residual radial magnetic fields, which mimic an EDM, the required precision of beam position monitors and a thorough understanding of systematic effects, as well as their mitigation, which may limit the sensitivity to a value larger than 10^{-29} e cm. The conclusion of the JEDI and CPEDM collaborations is that the accomplishment of the task requires a stepwise approach:

- Step 1: Proof of capability (ongoing activity): Perform R&D for key components and a first-ever deuteron EDM "precursor experiment" at the COSY-Jülich magnetic storage ring.
- Step 2: Proof of principle (time frame: next 5-10 years): Design, build and operate a prototype ring with beam kinetic energy between 30 and 45 MeV in two steps: (i) an all-electric ring for CW/CCW operation, but not at the magic momentum, and (ii) the ring with B-fields added for "frozen spin" operation to perform the first competitive proton (pEDM) experiment (with a sensitivity similar to the neutron EDM).
- Step 3: Precision experiment (time frame: next 10-15 years): Design, build and operate a dedicated storage ring (all-electric, kinetic energy 232.8 MeV) to push the pEDM sensitivity significantly below that of the neutron EDM; the final goal is 10^{-29} e cm.

The first objective is to convene and combine technological and scientific expertise in accelerator, nuclear/hadron and particle physics for a storage-ring EDM project. The emphasis will be on Step 2 as the inevitable milestone towards Step 3:

- Prepare a technical design study (TDR) for the prototype ring, then build and operate it. The ring layout should be host-site independent.
- Conduct a pEDM measurement as proof of principle and pave the way for the design of the final high-precision ring.
- In addition: use the prototype ring to conduct a dark matter (axions/ALPs) scan by searching for oscillating EDMs.

F. Abusaif et al. (CPEDM collaboration), *Feasibility Study for a Storage Ring to Search for Electric Dipole Moments of Charged Particles*, arXiv:1812.08535
Deliberation Document on the 2020 update of the European Strategy for Particle Physics (p. 16), June 2020; https://cds.cern.ch/record/2720131/files/CERN-ESU-014.pdf?version=1

European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures (ESCAPE)

by Giovanni Lamanna (CNRS, LAPP), international coordinator of ESCAPE

The European Union has launched the European Open Science Cloud (EOSC) initiative to support research based on open-data science. Astrophysics and particle physics are joining forces to create an open scientific analysis infrastructure in the cloud, linked to EOSC through the H2020 project ESCAPE – European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures. The ESCAPE international consortium addresses the open science challenges shared by ESFRI facilities (CTA, ELT, EST, FAIR, HL-LHC, KM3NeT and SKA) and other pan-European research infrastructures (RI) and organisations (CERN, ESO, JIVE and EGO). The presentation to ECFA explained the scope of this major project, the vision for open science and the need to go beyond the current state of the art to support the principles of FAIRness of data (Findable, Accessible, Interoperable and Reusable) in our research domain.

ESCAPE has recently implemented the first functioning pilot data-lake infrastructure, a new model for federated computing and storage designed to handle the (overall) exabyte scale of data volumes of next-generation ESFRI RIs (e.g. the HL-LHC) in ESCAPE. In collaboration with the various ESFRI project partners in the cluster, ESCAPE is developing, integrating into the EOSC portal and operating a dedicated catalogue of open-source analysis software. This catalogue will provide researchers with new software tools and services developed by the astronomy and particle physics community. ESCAPE will also strive to provide researchers with consistent access to a scientific data analysis platform. The "virtual research space" that ESCAPE aims to create will guarantee the acknowledgement and rewarding of researchers engaging in open transversal R&D in computing and software, as well as, potentially, a reference working environment for all next-generation facilities (such as the FCC). The cross-fertilisation environment and training actions provided by ESCAPE has enabled, for instance, the development of open-source original software (such as deep-learning algorithms and high-performance programming methods, among others), which is being included in the official analysis pipelines of some RIs that are partners in the cluster. All these actions and results are well aligned with some major recommendations contained in the 2020 European Strategy for Particle Physics. ESCAPE helps existing infrastructures, such as the Virtual Observatory in Astronomy, to connect to the EOSC. Finally, ESCAPE supports researchers who volunteer to participate in large human-powered research platforms (such as Zooniverse).

The presentation highlighted the synergies that ESCAPE has facilitated and an overview of the combined efforts of researchers in the Test Science Projects (TSPs). These are data analysis projects that correspond to some of the key transdisciplinary scientific objectives of the ESFRI facilities involved in ESCAPE in the fields of astroparticle, nuclear and particle physics, such as dark matter and the extreme universe phenomena. The idea is to exploit, for validation purposes, all the prototype services developed by the cluster, which are the building blocks of the ESCAPE virtual research environment. At the same time, the TSPs aim to promote and demonstrate the innovative impact of data analysis in open science. This approach was discussed at the last JENAS workshop in 2019 and the aim now is to link it to the joint ECFA-NuPECC-APPEC activities (JENAA). The ESCAPE project is halfway through, with 24 months remaining in which to complete its work programme.

The various synergies that the cluster has created, the frequent interactions with the European Commission and, even more importantly, those between the directors of the various RIs, make it possible to precisely evaluate the cluster's activities and set out relevant prospects for the future. At present, cohesion and cooperation is increasing among disciplines (e.g. between the five thematic science clusters). Other disciplines are getting organised, grouping together several RIs, often leveraging the corresponding science cluster, towards the creation of an ERIC or a League, or by building a thematic Community Platform Research Infrastructure. In such a scenario, the role of CERN as the HEP reference legal entity should be reinforced at EC level. Meanwhile, the successful experience in all five domains has demonstrated that the science cluster consortium scheme can be a potential sustainable model for a "coordinating structure" in Europe. A structure that spans a large research domain (namely astrophysics, nuclear physics and particle physics) is effective since it combines the formal commitment of the management boards of the relevant RIs (for top-down steering) with consultation of the community and national institutes thanks to the actions taken by ECFA or JENAA (for bottom-up engagement). Such an inclusive and coordinated structure can be thought of as a sort of "JENAA Community Platform Research Infrastructure", where JENAA (+Astronet) would play a key role in coordinating actions in view of the next EU research strategy and within the next Horizon Europe framework. Such a structure would be able to facilitate the establishment of a shared point of view on topical subjects, decide on coordinated actions and focus on upcoming joint R&D projects and commitments in response to major societal challenges in Europe, while also fostering connections with other "clusters".