ECFA

European Committee for Future Accelerators

ECFA Newsletter #2

Following the Plenary ECFA meeting at CERN, 15-16 Nov 2018

https://indico.cern.ch/event/759130/

Winter 2018

Thank you for your positive feedback on our first ECFA Newsletter, and please find in front of you the second issue, providing an overview of the topics discussed at the Plenary ECFA meeting held at CERN on 15-16 November. For the first time, we had a Plenary ECFA meeting open to the community at large, including webcasting and web recordings of the presentations, which are available at https://indico.cern.ch/event/759130.

ECFA has conducted a community-wide survey on the recognition of individual achievements in large scientific collaborations. More than 1300 participants expressed opinions on several statements relating to how they perceived the systems for recognition in their collaboration. On the occasion of the Plenary ECFA meeting, we disseminated the results to the community, and the document with the results is now available on the ECFA website: https://ecfa.web.cern.ch.

In odd-numbered years, the important EPS-HEP conference is held in the summer, including an open EPS-ECFA session, while in even-numbered years a Plenary ECFA meeting takes place around the same time of the year. Typically, the venue for the Plenary ECFA meeting is a major laboratory in the European region. A call for venues for the Plenary ECFA meeting in July 2020 has been issued among ECFA members, with a deadline of 15 February 2019.

The process of updating the European Strategy for Particle Physics has been formally launched by the CERN Council, as outlined on https://europeanstrategy.cern. Taking into account the input received from the community, an Open Symposium will be held in Granada (Spain) on 13-16 May 2019: https://cafpe.ugr.es/eppsu2019. In the context of exploring the Higgs sector, providing a coherent comparison of the discovery potential of all future collider programmes submitted to the European Strategy update is relevant yet challenging. With the aim of informing the debates, ECFA has helped the Physics Preparatory Group to create a working group of experts to map the landscape of Higgs physics research at future colliders. Ahead of the Open Symposium, the working group will work together with the PPG to provide a comprehensive and public report to inform the community.

Beyond the Open Symposium in Granada, at the upcoming EPS-HEP conference in Ghent (Belgium, http://eps-hep2019.eu), a joint ECFA-EPS open session will be held on 13 July 2019 to further the discussions relating to the update of the European Strategy for Particle Physics.

Together with ApPEC (Astroparticle Physics European Consortium) and NuPECC (Nuclear Physics European Collaboration Committee), an initial three-day joint seminar of the astroparticle, nuclear and particle physics communities is being organised for 14-16 October 2019 at Orsay (France). The joint seminar will inform the communities about each other’s scientific, technological and organisational challenges and opportunities, as well as identifying and exploring potential synergies and avenues for collaboration across the communities.

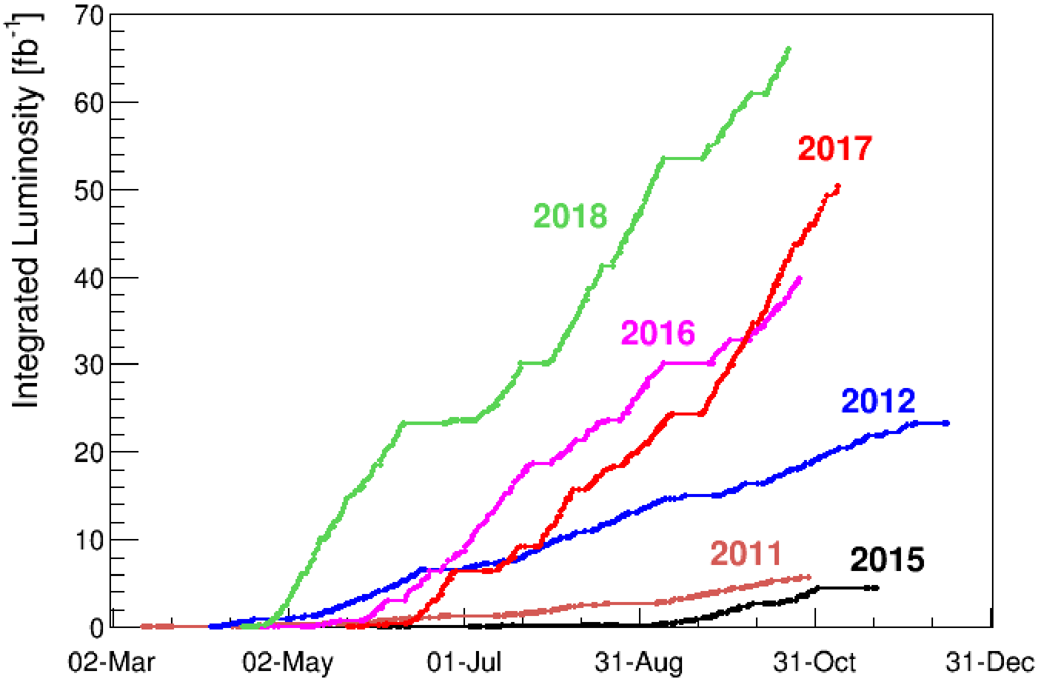
Jorgen D’Hondt, ECFA Chair
Carlos Lacasta, ECFA Scientific Secretary

Reports from laboratories in Europe

A standing item on the agenda of Plenary and Restricted ECFA meetings is a report from some of the major laboratories in Europe, *in casu* CERN, DESY and Frascati. These reports inform the community of new developments and opportunities and, within 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.

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

The presentation covered recent scientific highlights, the status of CERN's geographical enlargement and an update on the Science Gateway project. LHC Run 2 with protons ended on 24 October and the accelerator complex is now operating with lead ions. It was an extraordinary year for the injectors and the LHC, with integrated luminosities of about 65 fb^{-1} delivered to ATLAS and CMS (the target was 60 fb^{-1}) and 2.46 fb^{-1} to LHCb (the target was 2 fb^{-1}). The total integrated luminosity since LHC operation began (Run 1 plus Run 2) is about 190 fb^{-1} for ATLAS and CMS, to be compared with the goal of 150 fb^{-1}.



Integrated luminosity delivered by the CERN accelerator complex to the ATLAS and CMS experiments during the various years of LHC operation in Run 1 (2011, 2012) and Run 2 (2015-2018).

A large number of activities will be carried out during Long Shutdown 2 (LS2, in 2019-2020), including the upgrade of the injectors and the Phase 1 upgrade of the LHC experiments; the civil engineering work at LHC Point 1 and Point 5 to excavate the caverns, shafts and tunnels needed for the installation of the HL-LHC components; the consolidation of the insulation of the dipole diodes in order to be able to operate the LHC at the nominal centre-of-mass energy of 14 TeV as of Run 3; the installation of two pairs of new-generation Nb_3Sn dipoles providing a field of 11 Tesla; the connection of the Antiproton Decelerator (AD) experiments to the new ELENA ring; and the consolidation of the East Area at the PS. At the CERN Neutrino Platform, the single-phase liquid-argon detector prototype for the DUNE experiment at the Long Baseline Neutrino Facility (LBNF) in the US has successfully recorded first test-beam data and achieved levels of purity beyond the requirements. Other accomplishments and activities (e.g. the preparation of the input for the update of the European Strategy for Particle Physics by the CLIC, FCC and Physics Beyond Colliders projects, among others, and the recently achieved electron acceleration by AWAKE) were covered by other presentations at this meeting. Today, CERN has 22 Member States and 8 Associate Member States. Serbia is in the process of transitioning to full Membership, Croatia is in the process of becoming an Associate Member and Estonia has applied for Membership. Progress has been made on the Science Gateway project, which will see a new scientific education and outreach centre built next to the Globe of Science and Innovation. In particular, external donations of 57 MCHF have been secured so far, out of a total project cost of 79 MCHF, and the implementation plan was approved by the CERN Council at its September session. The (optimistic) goal is to open the centre to the public in 2022.

DESY – presented by Joachim Mnich (DESY Research Director)

At DESY, the European XFEL has entered routine user operation, recently reaching its full energy of 17.6 GeV and achieving the goal of 2700 electron bunches in the machine. In particle physics, the preparations for the LHC Phase 2 upgrades are progressing well, also thanks to the now largely commissioned new Detector Assembly Facility (DAF).

View of the CMS area of the DAF cleanroom at DESY, with microscopes and automated module assembly system. All major devices have been installed and are being commissioned.

The ATLAS and CMS groups are continuing their significant contributions to the physics harvest at the LHC. At SuperKEKB, DESY scientists and technicians are currently busy with, among other things, the installation of the pixel vertex detector (PXD). Beyond that, DESY is preparing to strengthen its on-site axion experiment portfolio: preparations for the ALPS II experiment are progressing well, aiming for data-taking commencing in 2020. The University of Hamburg, together with DESY, was successful in the nationwide "excellence strategy" competition: the excellence cluster "Quantum Universe" was granted funding and will give a further boost to particle and astroparticle physics in Hamburg.

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

The main activities at the Frascati Laboratory since the last Plenary ECFA meeting in July have concerned the completion of the beam line for the PADME experiment on dark photons, the continuation of the DAFNE set-up for the Siddharta2 run, and some preliminary evaluation of the possibility of operating the electron-positron machine as an accelerator test facility after the completion of the collider programme in 2020. PADME is in run since October, with plans to take data until the end of February 2019. Moreover, the experimental study of plasma acceleration at the SPARC_LAB laboratory has continued, in view of the future European FEL facility based on this technology. A new area devoted to a visitor centre was inaugurated in October, offering further opportunities for outreach relating to the Laboratory's activities.

A fish-eye view of PADME&BTF at the Frascati laboratory

Scheduled mid-term reports from 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 on the aspects raised in the reports.

Denmark – presented by Peter Hansen (University of Copenhagen)

Since the last visit of RECFA to Denmark in 2012, the economy has steadily improved. The expenditure for education is at the level of 6%. Generally, higher education produces good results, with fewer jobless graduates than in comparable countries, and the fraction of the population with a higher education is growing and is now at 40%. There is a high level of support for research. Also, the funding of basic research from private foundations such as Carlsberg, Novo Nordisk, Lundbech, Maersk and Velux is growing and is now a significant component. The particle physics community in Denmark consists of about 125 people, 76 of whom are CERN users. They are involved in ATLAS, ALICE, ISOLDE, ALPHA and NA63, and have an eye on future experiments. The phenomenological centre of excellence "CP3-Origins" at the University of Southern Denmark is now established and has grown to be one of the important theory centres in Europe. The first Danish experimental astroparticle activity has been firmly established at the University of Copenhagen and revolves around the IceCube Observatory at the South Pole. Funding for the upgrades of the CERN experiments, including computing, was approved in 2018. Half of the contribution to the ATLAS upgrade is yet to be secured. On the side of outreach, several new large-scale programmes are funded and have been launched, with a focus on primary schools.

Israel – presented by Eilam Gross (Weizmann Institute of Science)

Israel's excellence in physics is well reflected in its top success rate in attaining ERC grants. All branches of Israel HEP, namely EXP, APP, Pheno and Theory, face a bright future due to the recent recruitment of many bright junior faculty members, many of them starting new activities. To give a few examples, the HUJ in Jerusalem and BGU in the Negev have started particle physics phenomenology research, BGU has joined ATLAS's heavy ions activity and NEXT, and the WIS has become a major member of the XENON collaboration. The future of the Israeli contribution to ATLAS at CERN looks secured following the strong commitment of the teams to the operation, maintenance, analysis and upgrade, and the excellent recommendation of the evaluation committee appointed by the Academy in 2018. To maintain its high level of international involvement, nuclear physics in Israel requires sufficient funding and support from the government. All in all, after becoming a CERN Member State, Israel's mid-term HEP status in ECFA looks better than ever, with a rich future ahead.

Highlights from the ECFA European Survey on Detector R&D

by P. Allport, A. Cattai, S. Dalla Torre, D. Eckstein, E. Koffeman, L. Linssen, L. Serin, A. Straessner

During summer 2018, the ECFA Detector Panel launched a survey to gather input from researchers involved in R&D activities in astroparticle physics, nuclear physics and particle (including neutrino) physics in Europe. The survey intends to provide key insights for the preparation of a document to be submitted to the ongoing update of the European Strategy for Particle Physics.

In this newsletter, we report a few highlights from the statistical analysis of the survey; all survey questions, the data analysis, the results and highlights from ~2300 comments are summarised in a document available on the ECFA Detector Panel website: http://ecfa-dp.desy.de/e279752/. The survey itself is still open and available for further contributions at https://www.surveymonkey.com/r/DetectorsRD.

The information collected so far represents the involvement of 2890 FTEs from 37 countries, performing R&D exclusively for European projects. The positions covered by the FTEs at their home institutes (44% at universities, 37% at national laboratories and 7% at international laboratories) are reported in the table below. It is noticeable that there is an encouraging number of postdocs and students involved in this fundamental field of research.

Positions	% of FTEs involved in R&D
Professors	2
Physicists (permanent position)	24
Engineers (permanent position)	18
Postdocs	13
PhD students	19
Other students	11
Technicians	13

The R&D activities are performed in the context of experiments belonging to several branches of fundamental physics. The majority of FTEs (72%) are involved in activities for the field of particle physics. Hence, it is not surprising that:

a) almost 40% of the R&D activities concern vertex and tracking detectors realised in semi-conductors technologies;
b) almost half of the respondents to the survey are also involved in R&D in electronics and, in particular, in the development of a variety of FE ASICs in CMOS 65/130/180 nm nodes, technologies "*à la page*" for future particle physics experiments;
c) 75% of FTEs perform the R&D within their experiments, 18% within consortia and only a minor 7% independently within their institution.

One of the most encouraging results of the survey is that almost all respondents perceive their R&D activities as suited also to applications outside fundamental physics, namely in the fields of medicine, dosimetry, civil security, cultural heritage, nuclear control, photon science, geophysics, volcanology, industry, magnet-related activities, muon and large tomography, data handling, space, agriculture, optics, precision metrology, marine biology, the environment, high-tech engineering, telecommunications, etc. However, given this variety of possible applications, it is puzzling to see that in only 30% of cases are exploitation or technology transfer strategies embedded in the programmes. And, it is also surprising to learn that, when a technology transfer strategy is possible, almost 70% of the groups feel that they do not get enough support to solve financial, personpower, technical and legal issues.

Other forms of support were investigated, namely in terms of personpower, funds and access to common infrastructure and irradiation facilities. The results showed that excellent infrastructures are provided for the tests; the personpower is never sufficient; and there is a reasonable availability of funds, as shown in the table below. Nonetheless, it is worth noting that the vast majority of funds (>70%) are still from the home institutes or national funding agency and only some 20% come from EU programmes.

Support for personpower		**Funds availability**		**Access to test beam**		**Test beam infrastructures**		**Irradiation facilities**	
YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
35 %	65 %	55 %	45 %	92 %	8 %	88 %	12 %	89 %	11 %

According to this survey, R&D in Europe is reasonably organised centrally, but the system would benefit from the enforcement of regular international reviews, which should be robust, objective and scientifically critical. The obvious goal and advantage of more central organisation would be a reduction in the duplication of R&D efforts, leading to greater efficiency in the use of limited resources. Generally, a more effective use of resources could be achieved by clustering the R&D activities into bigger efforts and/or R&D collaborations. On the other hand, the fear was expressed that a more central top-down organisation could be counterproductive, as it might prevent new ideas, not deal well with conflicting constraints and, potentially, add bureaucracy rather than efficiency!

Initiatives towards enhanced collaboration and exchange of information between all physics communities are strongly recommended by 80% of respondents. In this context, there is a call to organise “exchange of ideas” platforms with a multidisciplinary approach, involving sources of new technologies and specialisations, which would provide opportunities for better use of the expertise available elsewhere.

Considerations of job, or career, opportunities for detector R&D experts in different domains are the last topic of this short summary. The results reported in the table below clearly indicate that our researchers perceive that there are much better prospects for employment in industry or in the tertiary sector than in academia or research institutes. Many of the respondents, who gave reasons for this, reported that “R&D activities are not considered to be as well rewarded as physics analysis and do not grant equal career opportunities”. This perception can be damaging, since there is a high risk that the best and most valuable people, after gaining expertise in this research field, then leave fundamental physics altogether.

Perceived opportunities for job/career	**YES (%)**	**No (%)**
in the field of research	39	61
in industry	66	34
in the tertiary sector, requiring advanced software development skills	80	20

Detector physics is a special, highly qualified branch of applied physics; it is the most obvious link between our frontier domain and social needs; it is a distinct field of great merits and is absolutely needed for the progress of fundamental research. Without intense R&D activities and advances in detector technologies, there will be no progress in physics outcomes, and we cannot allow this to happen.

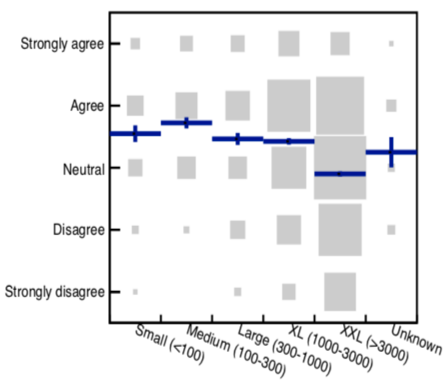
We conclude by thanking all the participants in this survey for their constructive input and for sharing with us many valuable thoughts and comments.

Recognition of individual achievements

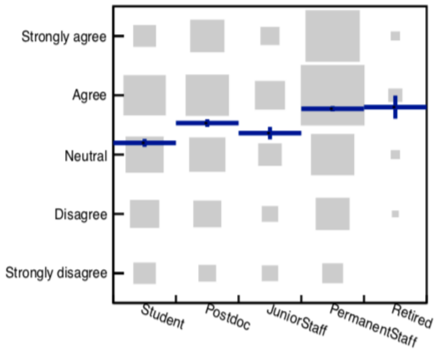
by S. Bentvelsen, J. D'Hondt, R. Forty, C. Lacasta, D. Milstead, P. Schleper, A. Zoccoli

The ECFA working group on the recognition of individual achievements in large scientific collaborations was created in spring 2018. Prior to the Plenary ECFA meeting at ALBA (Spain) in the summer of 2018, an initial survey was launched addressing the leaders of several CERN and CERN-recognised experiments. An overview of their replies was presented during the meeting at ALBA: https://indico.cern.ch/event/730568/. This mapped the landscape of what is currently being deployed in large collaborations to address the issue of recognising the achievements of individuals. The initiation of a second community-wide survey was discussed within Restricted ECFA and endorsed by Plenary ECFA. The opening of the survey was communicated widely, and the survey was closed on 26 October 2018 with a total of 1347 participants. The results were discussed within the working group and an extensive report is available on the ECFA website. During a dedicated and open Plenary ECFA session on the topic, after an inspirational talk by Valerie Gibson (University of Cambridge), the key observations from the survey were presented to the community. During the session a panel reflected on the presented results; the recordings are accessible on the website of the meeting. The panel members were, alphabetically: Rebeca Gonzalez Suarez (Uppsala University), Max Klein (University of Liverpool), Marek Lewitowicz (GANIL), Marcel Merk (NIKHEF) and Ulrike Schnoor (CERN). In this newsletter we briefly report on the discussions during that session.

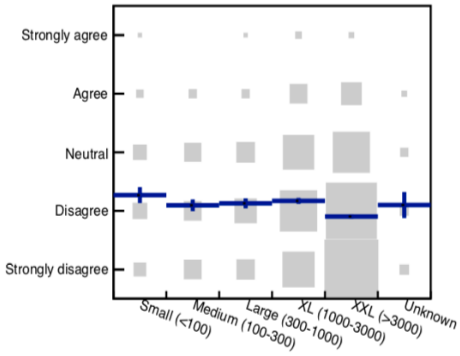
Researchers from most European countries are well represented among the participants in the survey, and over 80% of the participants are involved in the LHC experiments. Several researchers from non-LHC experiments in particle physics, nuclear physics and astroparticle physics also participated. Although 44% of the participants stated that they were permanent staff members at their institute, around 300 PhD students and around 440 postdocs or junior staff also participated. Participants were asked to indicate their level of agreement with a list of statements relating to elements of recognition of individual achievements. Each answer was quantified in a *score* ranging between strongly agree and strongly disagree, and the distributions of the scores were compared between groups of participants. The averages of the scores are also indicated on the figures. Responses were grouped according to the profile of the individuals, e.g. the career position, the experiment and the number of people in the experimental collaboration, the country or region of employment, age, gender, discipline, etc. Some observations are mentioned below, corresponding to points discussed by the panel.



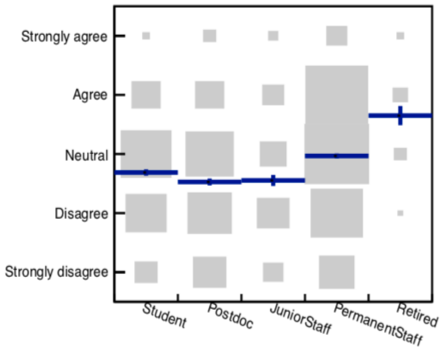
Conferences – *"The collaboration guidelines for speakers at conferences allow me to be creative and demonstrate my talents"*, versus size of collaboration. Overall, participants from LHCb agree more with this statement compared to those from CMS and especially ATLAS. For younger participants this is more pronounced. A conference talk is an outstanding opportunity for an individual to demonstrate to the community at large talents of creativity and scientific insight. Conference talks are perceived to be one of the most important aspects in verifying the success of a scientist.



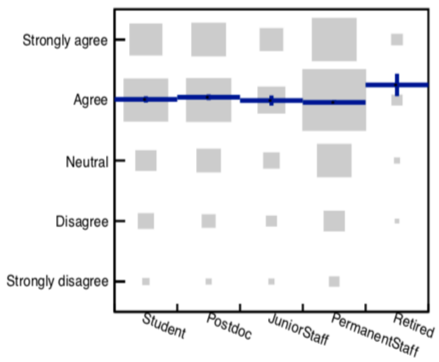
Publications – *"For me it is important to be included as author of all collaboration-wide papers"*, versus career position. Although it is somewhat less pronounced for participants from very large collaborations, the participants value being included as authors on these publications. The alphabetical listing of authors is supported overall by the participants, and this at all career stages. The participants in the survey have a divided opinion when it comes to alternatives.



Assigned responsibilities – *"I perceive that the profiles of positions of responsibility are well known outside the particle physics community"*, versus size of collaboration. The further away from the collaboration, the more challenging it becomes to inform people about the role of a convenor, yet the selection as a convenor is perceived to be a very important element in verifying the success of a scientist in our field. The majority of the participating early career researchers are neutral or do not agree with the statement that the process of selecting convenors is sufficiently transparent and accessible.



Technical contributions – *"I perceive that my technical contributions get adequate recognition in the particle physics community"*, versus career position. Technical work on hardware and software is at the core of experiments in particle physics, yet it remains challenging to recognise these contributions inside, and especially outside, the collaboration.



Scientific notes – *Scientific notes on analysis methods, detector and physics simulations, novel algorithms, software developments, etc. would be valuable for me as a new class of open publications to recognise individual contributions"*, versus career position. Although participants have a very diverse opinion when it comes to making the internal notes of the collaboration public, they would value the opportunity to write down their novel and creative technical ideas in a new class of public notes.

Beyond the dissemination of the results of the survey, ECFA will reflect on how, within its role, in can help to strengthen the recognition of individual achievements in large collaborations. The large scientific collaborations will be invited by ECFA to join a working group across the collaborations to further the discussion.

Future colliders

Following the discovery of the Higgs boson, and while the LHC experiments verify its relation to the Brout-Englert-Higgs mechanism of spontaneous symmetry breaking, the community is convinced of the presence of new physics phenomena that must complete the Standard Model of particle physics. Yet there are no clear indications as to where this new physics is hiding and how it will materialise. Therefore, experimental observations will have to guide us in our exploration. The LHC has a major role to play in this endeavour, but will have to be complemented with additional future colliders. To inform the community, we report in this newsletter on the open session of Plenary ECFA organised on the topic. All presentations, as well as their recordings, are available on the Indico page of the Plenary ECFA meeting: https://indico.cern.ch/event/759130.

The session started with comprehensive overviews of the status of the R&D towards novel technologies for future colliders and the relevance of these technologies in education and society. The remainder of the sessions provided overviews of all potential future collider projects inside and outside Europe.

RF Acceleration – Olivier Napoly (CEA/FNAL)

Three RF acceleration techniques are key to the construction of future colliders, with the two aspects of cost (fabrication and operation) and performance being critical.

1. Superconducting RF technology (SCRF) for high accelerating gradients (35-50 MV/m)
   The state of the art is set by the SCRF cryomodules of the European XFEL linac, reaching 26 MV/m on average, starting from 30 MV/m average cavity gradients. Increasing these gradients for the 35-45 MV/m range with Q_0 = 2e10 while reducing the overall costs is a realistic goal within a couple of years and could be achieved by improving the cavity preparation in industry, as demonstrated by recent R&D multicell cavity results, improving the RF distribution to operate individual cavities at their maximal fields, and robotising the module assembly.
2. Superconducting RF technology for continuous wave (CW) operation (100% duty cycle)
   The state of the art is set by the SCRF cryomodules of the LCLS-II project in the USA, reaching 20 MV/m at Q_0 = 2.7e10. The assembly of field–emission free cryomodules has also been demonstrated in the laboratories but it can be industrialised. The positive impact of the N_2-doping process to lower cryogenic losses has already been tested at the smaller RF frequencies needed for the circular colliders.
3. Room-temperature RF technology for very high gradients (100 MV/m)
   The state of the art is set by the accelerating modules of the SwissFEL linac (6 GHz), reaching 27.5 MV/m, and by 10-times-shorter CLIC modules (12 GHz) beyond 100 MV/m in the test stands. This technology surely offers much higher filling factors and real-estate gradient than SCRF. One of the main constraints is the very long conditioning time required to reach the low breakdown rates needed to operates tens of thousands of structures in overall stable conditions.

High-Field Magnets – Fernando Toral (CIEMAT)

High-field magnets are the key technology for a future high-energy circular collider. Magnets based on NbTi coils have reached their limit at the LHC, providing a nominal field of 8.3 T. During these last years, higher fields have been reached with accelerator magnets using Nb_3Sn coils, necessary for the HL-LHC project. The present dipole field record was achieved by the Fresca2 magnet, at 14.4 T.

A worldwide effort aims to develop 16 T dipoles, in the framework of different collaborations, such as EuroCirCol, the Future Circular Collider (FCC) study and the US Magnet Development Program. The main difficulties associated with these magnets are:

a) The improvement of the state-of-the-art conductor performance towards 1500 A/mm^2 and a cost of 5 EUR/kA.m at 16 T and 4.2 K.
b) The design of cost-effective 16 T dipole magnets with adequate electromagnetic and structural designs. The support structure is the main challenge. It must hold the large electromagnetic forces while maintaining the field quality and avoiding premature quenches.
c) The improvement of training, associated with the decision on the safety margin.
d) Magnet protection.

High-critical-temperature superconductors open the door towards dipole fields even beyond 16 T. The first efforts are being made in China, linked to the SppC proposal.

Plasma Acceleration – Allen Caldwell (*Max-Planck-Institut für Physik*)

Plasma wakefield acceleration comes in two variants: laser-driven (LWFA) and particle-driven (PWFA). In both cases, the transverse electric fields from the 'drivers' generate an oscillation of the plasma electrons and a 'bubble' structure in the plasma electron density that follows the driver. Electric and magnetic field strengths in the plasma can reach values several orders of magnitude higher than available in conventional technologies, opening a future for high gradient acceleration and thereby more compact accelerators.

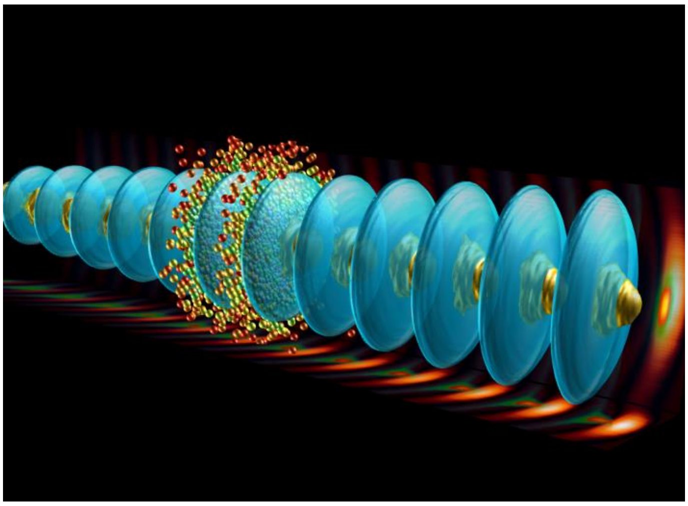


Image of a numerical modelling of the AWAKE plasma accelerator at CERN. Protons (bullet structures) excite a plasma wave (ellipsoidal forms) that accelerates electrons (coloured spheres) to high energy levels.

Credits: Jorge Vieira/IST Lisbon, Portugal

The state of the art in LWFA is from the BELLA facility at LBL (http://bella.lbl.gov), where an energy gain for electrons of 4.25 GeV was achieved in 9 cm. For PWFA, the record energy gain is 43 GeV in less than 1 m distance at SLAC (https://facet.slac.stanford.edu). Recently, a new approach using long bunches of protons has been started at CERN, the AWAKE experiment, and electron acceleration was demonstrated this year (https://awake.web.cern.ch). Important recent developments include demonstrating high capture efficiency in PWFA and the possibility of staged acceleration in LWFA (see previous web links). Milestones for the next developments include the demonstration of emittance preservation during injection and acceleration and the demonstration of positron acceleration. Although the primary high-energy physics goal of developing a high-energy and high-luminosity electron-positron collider is still distant, significant progress has been made and many exciting particle physics projects can already be envisaged based on plasma wakefield acceleration, including the search for dark photons in beam dump experiments, and fixed target experiments in new kinematic regimes. A 'super-HERA' based on proton-driven plasma wakefield acceleration, VHEeP, would also become a possibility. The future for plasma wakefield acceleration is bright!

Accelerator science education and schools – Elias Métral (CERN) *and G. Arduini, P. Burrows, N. Delerue, P. Lebrun, L. Rinolfi and H. Schmickler*

If Europe wants to prepare well for its future collider projects, education and training in accelerator science are crucial. Are we ready to educate the new generations of accelerator scientists? The answer is yes, but the effort should be pursued.

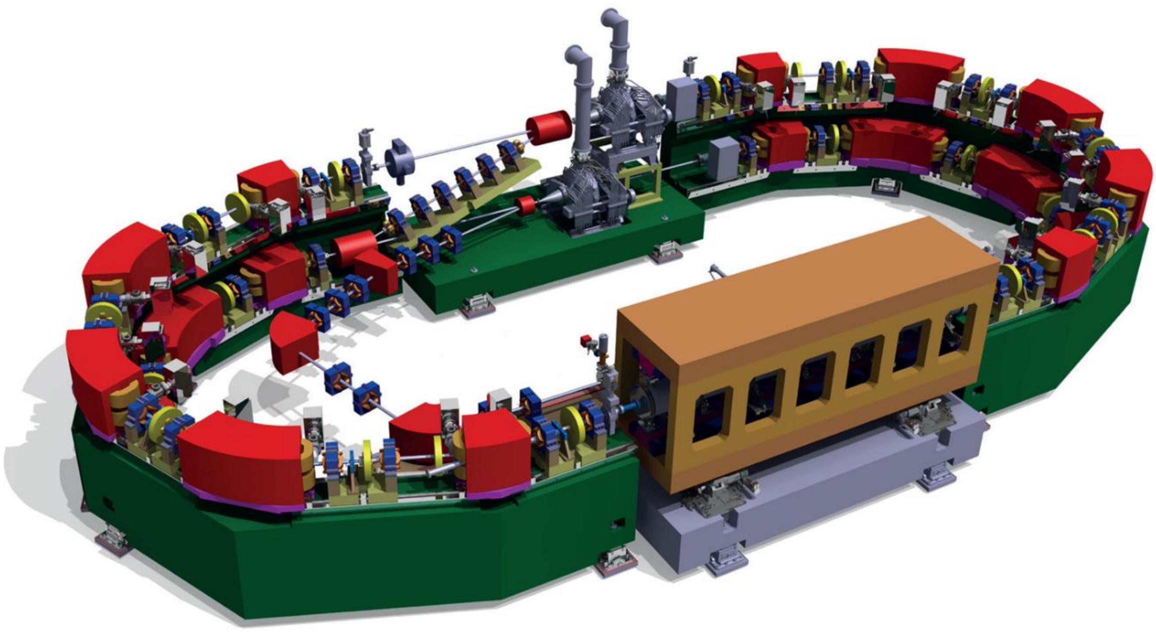
Between 2011 and 2015, a survey was performed within TIARA (Test Infrastructure and Accelerator Research Area, a project funded by the European Union Seventh Framework Programme), which highlighted the need for more training opportunities targeting undergraduate-level students. This need is now being addressed by the European Union H2020 project ARIES (Accelerator Research and Innovation for European Science and Society), with, in particular, the preparation of a MOOC (Massive Open Online Course) on particle accelerator science and engineering. The target audience is physics and engineering students at the undergraduate level, but the MOOC should be accessible to any interested person, such as professionals recently hired to work on a topic related to accelerators. This e-learning course, which should be released by May 2020, will be composed of four modules: introductory course (4 h), accelerator physics (6 h), accelerator engineering (6 h) and applications of accelerators (6 h).

When the decision is taken to build the future collider, everything should be in place with the CAS (CERN Accelerator School, since 1983), the CERN Doctoral Student programme (since 1985), the JUAS (Joint Universities Accelerator School, since 1994), the IAS for Linear Colliders (International Accelerator School, between 2006 and 2016: a future colliders school was created within the CAS in 2018 to cover both linear and circular future colliders) and the MOOC in preparation. With the latter, we will try to attract more students at universities, of which only a small fraction offer a formal graduate education in accelerator science and core technologies, in spite of an increasingly large economic and intellectual impact.

Accelerators for Society – Lenny Rivkin (PSI/EPFL)

Close to 40 000 accelerators around the world are in use today to analyse and modify the physical, chemical and biological properties of matter. These modern industrial and medical tools represent a market of close to 5 BUSD and are used in the production of close to 500 BUSD worth of goods. About 200 of them are used for fundamental and applied research, extending the tradition of building instruments to study nature around us that started with optical telescopes and microscopes. Accelerators have become an essential tool for research and have numerous applications that enable us to address society's essential needs.

The use of particle beams for combating malignant tumours is already well established in medicine. To date, more than 160 000 cancer patients worldwide have been treated with proton therapy, selectively removing cancer cells. It has become a method of choice for paediatric cancers. There are currently more than 60 proton therapy facilities in clinical operation worldwide. Pencil beam scanning, developed at PSI, is used in more than 70 per cent of proton beam treatments. The continued development of accelerator technology will make these devices more compact, lighter and more cost-effective in the coming years.



A novel compact (5 by 10 m) very bright EUV light source, COSAMI, is being developed at the Paul Scherrer Institute. It is designed for actinic mask inspection of the next generation of integrated circuit chips.

Accelerator technology also plays a key role in nuclear medicine. Today, many radioisotopes for diagnostics and therapy are produced with accelerators, mainly cyclotrons. Accelerators also play a major role in drug development, for example in determining the structure and composition of proteins in the membrane of cells. The resulting insights form the basis for targeted therapies adapted to the needs of individual patients.

Future generations of computer processors will be produced with accelerator-based light sources that generate short-wavelength light. The computer chips and data memories produced in this manner will give rise to significantly more computing power, faster data transfer and higher data storage densities. The recent development of novel imaging methods calls for more powerful and compact accelerators providing bright beams for biomedical applications as well as the semiconductor industry.

HL-LHC and HE-LHC – Patrizia Azzi (INFN-PD)

The Large Hadron Collider (LHC) is one of the largest scientific instruments ever built. To extend its discovery potential, the LHC will undergo a major upgrade in the 2020s to increase its luminosity by a factor of five and its integrated luminosity by a factor of ten, that is 3 ab^{-1} of data at 14 TeV centre-of-mass energy. The LHC results have so far confirmed the validity of the Standard Model of particle physics up to unprecedented energy scales and with great precision in the sectors of strong and electroweak interactions, Higgs as well as flavour physics, including top quark properties. The HL-LHC programme, thanks to a ten-fold larger data set, upgraded detectors and expected improvements in the theoretical understanding, will extend the sensitivity to new physics in direct searches for processes with lower production-section and harder signatures (e.g. extending the exclusion region for wino-like charginos by 500 GeV compared to Run 2). The major improvement in precise measurements of the Higgs properties (main couplings measured at the per cent level), SM observables (e.g. an overall uncertainty on $\sin^2\theta_{eff}$ below 18 x 10^{-5}) and the flavour sector may instead highlight anomalies due to new physics effects from higher scales. Most of the uncertainties will be dominated by the PDF knowledge, which will be significantly improved as well, in particular if an electron-proton run (LHeC option) is performed. Additional studies on the potential of a possible further upgrade of the LHC to a 27 TeV pp collider, the High-Energy LHC (HE-LHC), assumed to accumulate an integrated luminosity of 15 ab^{-1}, have also been made. A year-long workshop held at CERN brought together the experiments (ATLAS, CMS, LHCb, ALICE) and theorists to provide realistic expectations for the panorama of the knowledge that can be achieved by the HL-LHC programme as input to potential new projects; the results will be reported in a Yellow Report to be submitted to the European Strategy Group. The CDR of the HE-LHC proposal is available at https://fcc-cdr.web.cern.ch/#HELHC .

FCC-hh – Martin Aleksa (CERN)

The mandate of the FCC study group is to explore the feasibility of a pp-collider (FCC-hh) in the Geneva area (~100 km tunnel and 16 T magnets yielding a ~100 TeV centre-of-mass energy), with an electron-positron collider (FCC-ee) in the same tunnel as a potential first step, along with other possible options. This study is being summarised in the FCC conceptual design report (CDR, https://indico.cern.ch/event/750953/), which will serve as input for the European Strategy update in 2019/2020. A collaboration of 133 institutes and 25 companies in 34 countries has been created to carry out this task.

A 100 TeV pp-collider with an integrated luminosity of 20 ab^{-1} will extend the mass reach for direct discovery of heavy resonances by a factor of 5 to 6 with respect to the HL-LHC. It will allow us to measure the Higgs self-coupling with unprecedented precision of ~7% and to thoroughly examine the dynamics of electroweak symmetry breaking at the TeV scale, elucidating the nature of the electroweak phase transition. Similarly, FCC-hh will enable us to explore conclusively EW charged WIMPs as dark matter candidates.

FCC-hh requires high-quality accelerator magnets with a 16 T strong field. A focused R&D programme has been in full swing since 2014 to bring Nb_3Sn conductors to the required 1500 A/mm^2 current density at a temperature of 4.2 K. Worldwide magnet research collaborations have started work with the goal of producing short model magnet prototypes in the coming years. The implementation of a 100 km tunnel in the Geneva area has been studied and a possible location has been found, optimising the rock type, shaft depth, accessibility, schedule and costs. To best serve the research community, the future FCC-hh experiment collaborations will develop designs for complementary detectors. The baseline scenario includes four interaction points. An early detector design concept has been developed as a collaborative effort, based on experience from the LHC experiments, which demonstrates the feasibility of building experiments that will be able to exploit the full FCC-hh physics potential. The CDRs of the FCC proposals are available at https://fcc-cdr.web.cern.ch .

Ion and Ion-Electron colliders – Abhay Deshpande (BNL/Stony Brook University)

In 2015, the US Nuclear Science Advisory Committee (NSAC) in its ten-year outlook (Long-Range Plan 2015, https://science.energy.gov/np/nsac/) recommended a new high-energy, high-luminosity polarised electron-ion collider (EIC) as its highest priority for new construction. The EIC, with a centre-of-mass energy variable between 20-100 GeV (upgradable to 140 GeV), with polarised electron, proton, deuteron and helium nuclei, and unpolarised heavy nuclei, reaching an e-p equivalent luminosity of $10^{33\text{-}34}$ cm^{-2}sec^{-1}, would be the ideal facility to explore the role of gluons in QCD. It will image the dynamics of quarks and gluons inside nucleons and nuclei and help us understand their emergent properties, such as their mass and spin. With heavy nuclei at high energy, the EIC will be able to probe highly dense gluonic systems predicted by QCD in all nuclei as a result of non-linear interactions amongst the gluons. A novel form of matter called the Color Glass Condensate (CGC) is of broad interest because it could not only shed light on QCD dynamics at high energies but, once understood in terms of QCD formalism, scientists could use that formalism in other field theories (QED and gravity) where creating and studying such non-linear dynamics experimentally is difficult. Such a comprehensive study of QCD made possible by the EIC, through the imaging of nucleons and nuclei, is hence not only important for nuclear and particle physics but may prove important for other fields of physics. The science goals of the EIC are summarised in the community-led EIC White Paper (*EPJ A (2016)* ***52*** *268*).

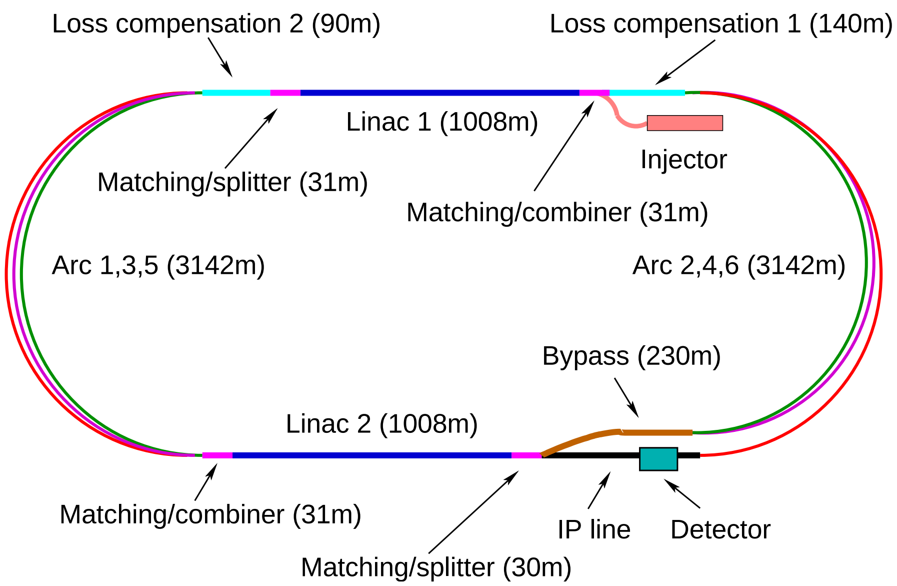
There are currently two possible realisation plans being developed for the US EIC. One is at BNL, in which a 5-18 GeV/c electron beam facility would be added to the existing RHIC tunnel to collide with one of the existing beams of RHIC, hence called eRHIC. Another option at Jefferson Lab would extract the electron beam from the CEBAF and collide it with a beam from a new hadron beam facility to be built in its vicinity. This is called the JLEIC.

Encouraged by the strong recommendation from the US NSAC, a worldwide EIC Users Group (EICUG, www.eicug.org) was formed in 2016. It currently comprises ~840 PhD members from 177 institutions in 30 countries. In its report of July 2018, the National Academy of Sciences, Engineering and Medicine (NAS) suggested that the science of EIC is compelling and fundamental and the realisation of the facility is timely: http://nap.edu/25171.

LHeC/FCC-eh (incl PERLE) – Uta Klein (University of Liverpool)

The Large Hadron Collider determines the energy frontier of experimental collider physics for the next two decades. The High-Luminosity LHC could be further upgraded with a 60 GeV energy, high-current electron beam by using novel energy recovery linear accelerator (ERL) techniques, which enable TeV energy scale electron-proton collisions at 1000 times HERA's luminosity. A joint ECFA/CERN and NuPECC initiative led to a detailed conceptual design report in 2012 for this project, dubbed LHeC. Since then, the LHC has performed in a magic way and the Higgs boson has been discovered, which motivated representatives of about 150 institutes to proceed with the development of the accelerator, physics and detector prospects for ep and pp twin-collisions at HL- and HE-LHC, as well as at FCC, which are being prepared for publication in early 2019. This big step in sustainable accelerator technology is being prepared by an international collaboration intending to build a 10 MW model of a multi-turn ERL, PERLE at Orsay.

Electrons for CERN's hadron colliders would be like "Hubble telescopes" of the micro-universe, directed to unravel secrets of the complex dynamics of the strong interaction, as those also demand. The substantial increase in luminosity and of the kinematic range make the LHeC, and its possible successor, the FCC-eh, unique colliders, complementary to the ee and hh machines, which could test the Standard Model deeper than ever before, and possibly discover new physics in the electroweak and chromodynamic sectors. This would also found a novel Higgs facility, moving the hadron collider Higgs programme a major step forward. Not least, the LHeC would become the most powerful electron-ion research facility one could build in the coming decades to resolve the chromodynamic origin of the quark-gluon plasma and the unknown partonic substructure and dynamics inside nuclei. More information at http://lhec.web.cern.ch .



LHeC footprint of a 9 km circumference, three-turn ERL structure, tangential to the hadron beam line, which could be arranged at IP2. The ERL delivers 20 to 60 GeV electrons that are scattered off LHC hadrons concurrently to the hh interactions. Experimentation at LHeC would be with a newly built detector, which could be inserted during a two-year shutdown. All installations are decoupled from LHC operation.

Colliders for b/c/tau production – Alexander Bondar (Budker INP/Novosibirsk State University)

Experiments at the LHC constituted the focus of the high-energy physics community during the last decade. After the discovery of the Higgs boson, strong efforts have been applied to direct searches for new particles, mainly supersymmetric partners. The LHCb experiment is continuing the programme of precision measurements of heavy flavours and providing many interesting results, including those on the violation of flavour universality. The Belle II experiment is a substantial upgrade of the Belle detector and operates at the SuperKEKB energy-asymmetric e^+e^- collider. The accelerator has completed the first commissioning phase, and the first collisions were delivered in April 2018. The design luminosity of SuperKEKB is $8x10^{35}$ cm^{-2} s^{-1}, and the Belle II experiment aims to record 50 ab^{-1} of data, a factor of 50 more than the Belle experiment. The advantages of the Belle II experiment at the SuperKEKB B-factory with respect to a hadron-collider experiment are:

- a full solid angle detector coverage;
- the relatively clean environment of e^+e^- collisions w.r.t. a hadronic environment;
- the possibility of reconstructing the complete final state.

A relatively low background environment makes excellent reconstruction and identification of the final system with photons possible. Due to the low track multiplicity, the detector has high B, D and τ reconstruction efficiencies. As a result, B factories are also charm and τ factories. Since e^+e^- collisions produce clean samples of B mesons from the initial Y(4s) state, missing-mass analyses based on the energy-momentum conservation law can be performed. At lower peak luminosities and serving the machine commissioning, the first physics data-taking period started in April 2018 (i.e. Phase 2). A new data-taking period (i.e. Phase 3) will start in February 2019, and the peak luminosity is expected to increase to the design value, while the background is expected to become significantly higher. From Phase 3 onwards, the fully upgraded detector will be in place.

B factories provide huge statistics of tau leptons and charm particles, allowing searches for rare and suppressed decay modes. Although a super-charm-tau factory (Super-CTF) can't compete in the number of tau leptons, it can probably provide better background conditions in some important physics cases. Such a high luminosity machine with a particle detector designed for precision tau physics may help to develop this not-yet-explored and underestimated corner of particle physics. Longitudinal polarisation of the electron beam increases the sensitivity to CP violation in tau decays and helps in the measurement of the Lorentz structure of leptonic tau decays. Similarly, these factories may have certain advantages compared to the B factories because of the exclusive production of charmed particle pairs. It is generally believed that experiments at a Super-CTF with an integrated luminosity of 1-2 ab^{-1} will be complementary to those at B factories.

A Super-CTF is proposed for the Budker Institute of Nuclear Physics in Novosibirsk. An e^-e^+ collider covering a centre-of-mass energy range from 2 to 6 GeV with a maximum luminosity of 10^{35} $cm^{-2}s^{-1}$ is designed to study physics of tau leptons and charmed hadrons. Another tau-charm facility has been proposed by high-energy physicists in China to replace the BEPC II after its retirement and before the construction of CEPC. This new CTF has been named High Intensity

Electron Positron Accelerator (HIEPA). It would be a next-generation electron-positron collider operating in the centre-of-mass energy range from 2 to 7 GeV, and with a nominal luminosity of 10^{35} $cm^{-2}s^{-1}$. Both proposals include a longitudinal polarised electron beam. The main challenge for the realisation of these projects is to increase the involvement of active research groups around the globe in an international collaboration.

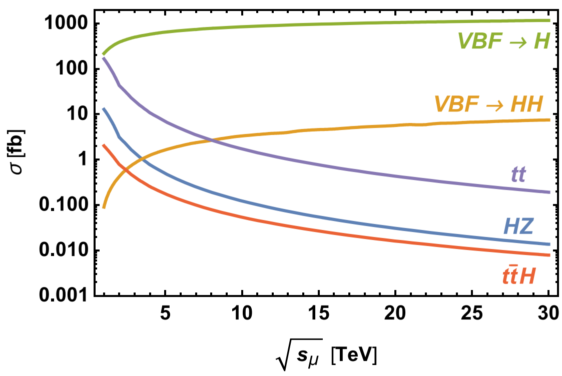
Muon colliders (incl MICE) – Nadia Pastrone (INFN-Torino)

Muon-based technology represents a unique opportunity for the future of high-energy physics research: multi-TeV energy domain exploration. Muons are point-like particles, with a mass about 200 times larger than that of the electron. They can be accelerated in a multi-pass ring without limitations by synchrotron radiation, while all of the beam energy is available for the hard collision. The short muon lifetime at rest, and the difficulty of producing large numbers of muons in bunches with small emittance, are the main challenges to address. Therefore the design of a muon collider requires the development of innovative concepts and demanding technologies to reach adequate instantaneous luminosity. The beam background from the decay of the muons has an impact on both machine and detector layout, and possible significant radiation at the surface must be mitigated.

The US Muon Accelerator Program (MAP 2011-2014) provides a well-documented set of studies and measurements on the proton-driven option. The MICE international collaboration recently reported the pioneering observation of the ionisation-cooling of muon beams, well described by theory and simulations. A final cooling scheme has still to be studied.

The novel approach of the Low Emittance Muon Accelerator (LEMMA) is based on muon pair production at threshold with a positron beam impinging on electrons at rest in a target.
Generating small emittance muon beams, without any need for muon cooling, would make it possible to reach high luminosities with much smaller beam currents and consequently reduced detector background and surface radiation. The positron driver concept needs to be consolidated to overcome the main technological challenges and to provide an end-to-end design. Detailed studies and R&D are still required to design a feasible solution for a muon collider, and must be planned and pursued at international level, in synergy with other projects.

A 14 TeV muon collider provides an effective energy reach similar to that of the 100 TeV FCC. The centre-of-mass energy in colliding muons could potentially go well beyond 14 TeV, allowing precise measurements to be taken in the Higgs and top sector (see figure) and a new frontier to be explored.



Muon-based facilities offer unique potential to provide a next generation of capabilities and world-leading experimental support, spanning physics at both the intensity and energy frontiers.

CEPC and SppC – Qin Qing (IHEP)

As a Higgs factory proposed by IHEP, China, in 2012, CEPC (Circular Electron Positron Collider) is a very ambitious and important high-energy physics facility, aiming at various physics at ZH (240GeV), WW (160GeV), and Z (91GeV) production, with the highest luminosity ever achieved by a collider in the world. Since 2012, both the accelerator and the detector of CEPC have been studied carefully and most designs fulfil the requirements of the physics goal and key hardware. The CEPC CDR, including accelerator and detector design, has been finished and was published officially on 14 November 2018 (http://cepc.ihep.ac.cn/), with a 100 km double-ring scheme as its baseline design. Its site investigation and engineering implementation have also been in progress in recent years. Now, the Chinese government is interested in large scientific projects and we are actively making an application to build CEPC. Some design and R&D budgets are funded from different resources for the CDR study and the future TDR task. After the construction of the CEPC, data-taking will be expected according to the physics requirements. In the second stage, a super proton-proton collider (SppC), will be built in the same tunnel as the CEPC as a discovery machine to explore the energy frontier of elementary particle physics. The key technology of the HTS magnet of SppC is gradually being developed, with support from industry in China.

FCC-ee – Patrick Janot (CERN)

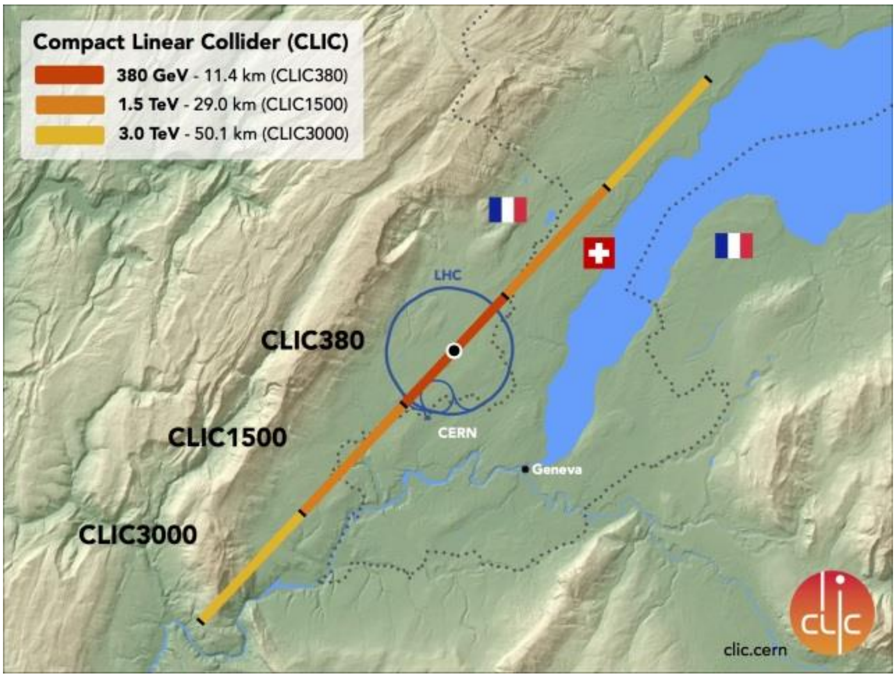
Since its inception, the FCC collaboration has aimed to deliver the e^+e^- collider conceptual design (FCC-ee) that best complies with the ESPP 2013 guidelines and offers the broadest discovery potential. In addition, it is the first step of a most ambitious programme of at least 60 years of physics at the energy frontier. The FCC-ee enjoys a mature technology that combines 50 years of experience with circular e^+e^- colliders with novel ingredients, and offers the highest luminosities in the 88 → 365 GeV centre-of-mass energy range. The FCC-ee discovery potential is multiplied by the presence of the four heaviest SM particles (5.1012 Z, 108 W, 106 Higgs and 106 top) in its energy range, by the possibility of multiple detectors, and by the unique ability to measure the centre-of-mass energy with a precision of 100 keV. Within the 15-year programme of the FCC-ee, the precise measurements of the properties of these particles (as well as b, c and tau) can probe new physics effects at scales as high as 10 to 100 TeV. It offers unique opportunities far beyond electroweak and Higgs measurements: other signals of new physics could arise from the observation of minute flavour-changing neutral currents or lepton-flavour-violating decays, from the observation of dark matter in Z and Higgs invisible decays, or from the direct discovery of particles with extremely weak couplings in the 5 to 100 GeV mass range, such as well-motivated right-handed neutrinos and other exotic particles. The FCC-ee is able to fully characterise the Higgs boson (including the ttH coupling and the Higgs self-coupling) in a model-independent way, but is much more than a Higgs factory. The robust and mature design of the FCC-ee gives the opportunity to start physics seamlessly at the end of HL-LHC. The CDRs of the FCC proposals are available at https://fcc-cdr.web.cern.ch .

ILC – Marcel Stanitzki (DESY)

The International Linear Collider (ILC) is a proposed 250 GeV e^+e^- linear collider that is currently under discussion in Japan. It provides polarised beams and two interaction regions and, as a linear collider, is easily extendable to higher energies to reach the top quark pair threshold or to study Higgs self-coupling. The main physics motivation of the 250 GeV ILC is to study the Higgs boson with great precision. The ILC accelerator is a 20-km-long linac based on superconducting RF technology. The European XFEL, which is operating at DESY, is using similar cavities and has demonstrated the viability of this technology on a large-scale facility. The R&D on superconducting RF is continuing and pushing the accelerating gradient, as well as the quality of the cavity. The detectors for the ILC, SiD and ILD are based on particle flow and are mature concepts that have been through many reviews. An active R&D programme for ILC detectors is underpinning these efforts. Their physics performance has been evaluated using full simulation and reconstruction. The ILC is currently under government review and Japan is expected to make a statement before the end of the year, accompanied by increasing activity at the diplomatic level worldwide. More information is available at https://linearcollider.web.cern.ch/content/ilc-european-strategy-document.

CLIC – Aidan Robson (University of Glasgow/CERN)

The Compact Linear Collider, CLIC (http://clic.cern), uses high-gradient room-temperature structures in a two-beam acceleration scheme to reach multi-TeV electron-positron collisions. The key accelerator challenges have been demonstrated: production of a high-intensity drive beam with the required stability, power transfer from the drive beam to the main beam providing gradients well above 100 MV/m, cavities that operate at 100 MV/m with a low breakdown rate, and the alignment and stability required for nanometre-sized beams. CLIC technology is increasingly being applied in projects worldwide, and benefits from close collaboration with light source linacs and rings, both existing and planned. A staged approach will provide collisions at centre-of-mass energies of 380 GeV, 1.5 TeV and 3 TeV. For the initial stage, the power requirement is <200 MW and the cost is around 6 BCHF. Construction would take around seven years and could begin around 2026.



CLIC offers the precision measurements possible at a lepton collider, while uniquely reaching multi-TeV energies. It offers a comprehensive Higgs and top-quark physics programme, including sensitivity to the Higgs self-coupling at the 10% level, and excellent reach for many

Beyond-Standard-Model scenarios. Many new studies this year exploring CLIC's BSM sensitivity are gathered together in the Yellow Report "The CLIC Potential for New Physics". Highlights include Standard Model Effective Field Theory fits of precision observables, which benefit from the high-energy stages, and a wide range of sensitivity studies for new physics scenarios, including extended Higgs sectors and dark matter candidates. The proposed CLIC detector model is mature and well understood, with an R&D programme continuing on CLIC-specific requirements, such as low-mass vertex and tracking detectors with nanosecond timing. CLIC is producing several additional Yellow Reports in advance of the European Strategy, including a Project Implementation Plan and a Summary Report. All documents are available at http://clic.cern/european-strategy .

Announcements

Registration for the Open Symposium of the update of the
European Strategy for Particle Physics
(Strategy website: https://europeanstrategy.cern/)
(Open Symposium website: https://cafpe.ugr.es/eppsu2019/)