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EuCARD-2

Enhanced European Coordination for Accelerator Research & Development

Newsletter

Accelerating News Issue 19

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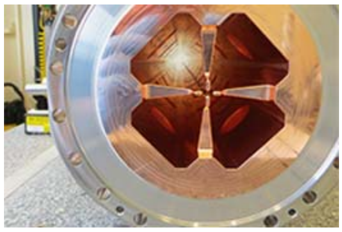

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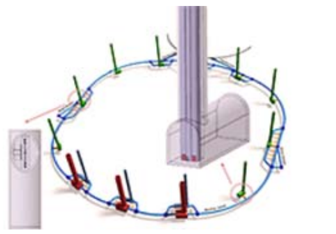

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HiL

A year of successes for HL-LHC

by Isabel Bejar Alonso (CERN)

180 HL-LHC project members participated to the 6th Annual Meeting in Paris from the 14th-16th November, co-organized with CEA at the "Espace Saint Martin" premises (Image: CERN, HL-LHC collaboration)

2016 has been a very busy year for the Hi-Luminosity team. In March, the HL-LHC was declared as an ESFRI landmark, and in June the project received the formal approval of the CERN Council. Finally, after an international review, the 2^{nd} HL-LHC Cost and Schedule review took place in October; where a group of international experts scrutinized the status of the project. The reviewers gave very positive feedback and pointed out risks of which the management team were already aware.

On the technical side, it is difficult to determine the three main technical milestones of the project due to the sheer volume of achievements.

For Lucio Rossi, HL-LHC Project Leader, 2016 was the year of the consolidation of the civil engineering and technical infrastructure design. In particular, in 2016 we optimized the so called “double decker” solution, which was selected in summer 2015 as best solution for hosting the technical services that will feed the new insertion regions in a gallery a few meters above the main LHC tunnel.

This definitive design pushed to a re-baselining exercise which aimed to resolve the excess in civil engineering costs that emerged in spring 2016. The results of this exercise were presented and validated at the Cost and Schedule review after being approved by the CERN Executive Committee in August. The results have also been integrated into the latest version of the Technical Design Report (TDR), that will be published soon.

In addition, Lucio Rossi pointed that the HL-LHC technical teams have achieved many things, such as the production of full cross-section models of the HL-LHC’s future quadrupole magnets. The first short model (MQXFS1) of the future quadrupoles was produced by a collaboration between US-LARP and CERN. The magnets (MQXFS1) achieved the ultimate gradient and retained it after a thermal cycle showing an optimal memory. Had the magnet been a prototype rather than a model, would have been qualified for installation.

Furthermore, the SPS testing of the crab cavity cryo-assemblies has also made significant progress. After being considered in a critical state and with challenging planning just one year ago, the schedule is back on track and has been adhered to, without any further delay.

Beyond SPS testing, the industrialization plan for the HL-LHC production was validated by the external reviewers and considered extremely solid.

HL-LHC has had a successful year both in terms of project management and technical milestones. Project members gathered for the 6th HL-LHC Collaboration meeting held in Paris in November to discuss the past year and look forward to the next steps.

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EuPRAXIA baseline parameters established

by Dr. Ricardo Torres (University of Liverpool)

Photograph of the participants at the 1st Yearly Meeting of EuPRAXIA (Image:Copyright Pieyre Sylvaine, LLR)

The First Yearly Meeting of the EuPRAXIA consortium took place at the École Polytechnique in Paris, over 26-28th October. Ralph Assmann, Project Coordinator, and Arnd Specka, Deputy Project Coordinator and Host of the meeting, welcomed 59 registered participants from partner institutes, associate partners, and industry.

The Yearly Meeting discussed the fruitful first year of the project, which included the forming of the collaboration board, hiring of new personnel, investigation of facility parameters and a total of eleven workshops and special work package meetings. Scientific results from these events covering all aspects of the project were reported, and included interesting new insights and future directions.

One of the highlights of the meeting was the presentation and approval of the preliminary study concept of EuPRAXIA. The report summarized the scientific input for the preliminary study concept of EuPRAXIA which has been received over the past year. All work packages contributed to this report with summary reports of topical workshops held during 2016.

One such workshop was the European Plasma Accelerator meeting held in Pisa in June 2016,

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where more than 120 scientists gathered and discussed the various technical approaches and requirements for the collaboration over three days. Another workshop on laser technology which lead to the 100-cube laser challenge (100J / 100fs / 100Hz) has become one of the baseline components of the EuPRAXIA design.

The preliminary study concept report presents the outcome of all these discussions, condensed into flow diagrams and technical tables. The graphical diagrams show the main concepts, their interplay and the connections to relevant applications. Included in the report are the agreed baseline parameters, the parameter ranges to be explored and the technical goals for the next step of the EuPRAXIA conceptual design work.

The values of the parameters were first derived from scaling laws and refined by simulations. The parameter ranges documented in the report will ensure that work done in different locations by the project partners will be focused on the same targets and operating under the same assumptions. This common baseline for parameters and their study range will also ensure that results can be compared for beam quality, tolerances, layout footprints and costs.

At this stage, the study will contemplate multiple paths for obtaining high-quality multi-GeV electron beams. Such concepts considered include: Laser Wakefield Acceleration (LWFA) with internal or external injection and direct or staged acceleration to 5 GeV; beam-driven Plasma Wakefield Acceleration (PWFA) to 1 GeV or 5 GeV; and a hybrid scheme including LWFA and staging using PWFA to a multi-GeV electron beam.

By keeping these common baseline parameters and goals in mind, the work packages of EuPRAXIA can further investigate the techniques and approaches required.

In addition, the report contained the requirements for the plasma-based accelerator and its experimental user areas tailored for the two main applications foreseen by EuPRAXIA. Firstly, High Energy Physics and other pilot applications, and secondly, a Free Electron Laser (FEL) for ultrafast photon science.

The values for the FEL requirements were determined during several workshops held over the last six months. The requirements for the HEP applications in terms of beam parameters and infrastructure were defined by the participants of a workshop on Pilot Applications of Electron Plasma Accelerators (PAEPA) in mid-October 2016.

In the next phase of the project, the technical work will use the parameters from the preliminary study to provide a more refined table of parameters for incoming and outgoing beam and laser properties, realistic estimates of performance, basic values for tolerances and stability requirements, basic layouts (footprints) of the technical components, and a further iteration of specifications for the science applications.

The future outcome from the work packages could be used to rank the various solutions towards the final proposal, due in 2019. This ranking will define the optimal combination of technologies for the conceptual design of a EuPRAXIA facility.

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Interview with Jon Butterworth

by Panos Charitos (CERN)

Prof Jon Butterworth (University College London) is Head of the UCL Physics Department and member of the ATLAS Collaboration (Image: Macleans.ca)

Panos Charitos of Accelerating News sat down with John Butterworth, Head of the Physics Department at University College London (UCL) and author of the book "*Smashing Physics: The Inside Story of the Hunt for the Higgs*" to discuss his work. We covered his involvement in one of the most important physics discoveries, the present landscape in high-energy physics and the plans for future colliders and ongoing R&D efforts that inspire technological innovation and could lead to ground-breaking science in the course of this century.

PC: What is your view on the latest results from the LHC and other experiments presented earlier this summer in ICHEP16 ?

JB: From the point of view of the experimentalist, the LHC has done an incredible work offering a significant leap in the energy scale. The fact that the 750 GeV bump was not confirmed caused some disappointment but this doesn't mean that our search for new physics came to an end as we have just started scratching the surface.

Perhaps one could compare the situation with the first flight over a newly discovered island, where new physics may lie. We first fly at 30,000 ft., which is what we did in 2015, and then at 10,000 ft., where we may see signs of a new civilization. However, discovering nothing unexpected does not mean that there is no new physics on the ground. We just have to land carefully and explore the territory in detail.

On the one hand, it would be great to have a breakthrough discovery announced at ICHEP 2016, but on the other hand, the fact that the accelerator and detectors are doing so well means that we experimentalists have a lot of work to do.

It seems strange that nothing has appeared yet, but the next discovery may be just around the corner and there might be something to discover in higher energies. I would like to see the theoretical net cast a little wider. In any case, however, I am looking forward to the next three years for more data with higher precision.

PC: Do we need a new way of interpreting experimental results given the success of the Standard Model?

JB: Presently we experience a strange situation, because the Standard Model of particle physics — so complete and consistent that every calculation fits new data with remarkable accuracy not to mention the fantastic success of the Higgs discovery— leaves a number of questions open. It does not explain dark matter nor what caused the observed matter–antimatter asymmetry; both are fundamental problems that challenge our present understanding of nature.

In other words, the more we look closely at the Standard Model, the more surprised we are at its success. Looking at the latest results, I think that a large part of the motivation for theories postulating new physics tied to electroweak symmetry breaking is becoming slightly less attractive.

So to answer your question, I think that there might be more to it than we thought and maybe approaching it from a different angle will reveal answers to some of the open questions Maybe the Standard Model is even more wonderful than it appears.

PC: To which extent should the concept of naturalness continue inform our research?

JB: We know that at the LHC energies special things happen in physics. The force carriers of the weak interaction – W and Z bosons – have masses in this energy range and we have discovered a Higgs boson with mass lying in this energy range.

However, from our theory, the Higgs mass gets lots of big quantum corrections, positive and negative, which cancel each other out in an apparently miraculous way for the Higgs mass to be where we see it. The exact cancelation of terms seems a bit strange to be merely a coincidence of the model. . In this context, naturalness is the assumption that the parameters in a theory should be about unity, and should not have to be fantastically fine-tuned in order to make the theory work.

Supersymmetry tries to answer this question by avoiding the concept of fine-tuning. It does so by introducing a new particle for every existing one, with the opposite sign thus accounting of all these cancellations that we observe. However, though it is conceptually a beautiful theory there is yet a lack of experimental evidence to confirm it.

The concept of naturalness boils down to the so-called Hierarchy problem and is related to the fact that we have different hierarchy scales: the QCD scale, the electroweak scale and the Planck scale at very high energies. The electroweak scale is closely linked to the mass of the Higgs boson but we still don't know why the Higgs boson has a mass at this energy scale and how to deal with the quantum corrections predicted by the theory. Theories like supersymmetry are introduced to cancel those corrections and thus make it more natural to have this mass. Usually a lower than expected energy scale for the mass of a particle, as in the case of pion mass, is due to an approximate symmetry. In the case of the electroweak scale the approximate symmetry would be supersymmetry that fine-tunes the Higgs mass to where we see it.

To conclude, naturalness presents an interesting problem in modern physics which becomes very pressing in light of recent LHC data. The motivation for and significance of naturalness in quantum field theory is a hotly contested topic that we need to rethink. A concept which I think may evolve – rather than guide- as we get more data from the LHC and other experiments. On a personal note, I think that we have other reasons to believe that the Standard Model is not the whole story, with dark matter being one of the main motivations for future research.

PC: How important is our understanding of gravity for answering some of the open questions?

JB: Presently the best theory we have for the description of gravitiy is the General relativity which explains the geometry and development of the universe on macroscopic scales. Quantum field theory, in the Standard Model of particle physics, describes the other three fundamental forces and describes the universe of the very small.

However, at very high energies their spheres of applicability - the very large and the very small - overlap, and the theories conflict. Both cannot be valid and it seems that we still lack a more profound understanding.

We face a great anomaly which is the absence of any treatment of gravity on the same footing as the other forces. There is a hierarchy problem of gravity being so ridiculously weak compared to the other forces while the same applies to the masses of particles like neutrinos that are extremely small compared to other particles. These two apparent unrelated observations may be linked and could mark a radical shift in our understanding of nature as well as to rethinking or rephrasing some of the so-called open questions.

PC: How could we decide about the next step in particle physics research?

JB: We need to understand the scale at which new physics may exist. Before committing my scientific career, I would like to know that there is an energy scale after which physics is not the same. In the case of the LHC — although there are still many ongoing searches — we knew that it could answer whether the Standard Model Higgs boson exists. We need a similarly well-posed question about the new leap in energy.

In the meantime I think is important to work on R&D to make future high-energy accelerators cost-effective, as well as diversify our experiments until we find a clue of new physics and think how we could probe it. I hope that this would be within the reach of a 100 TeV machine and I would love to work towards this direction to explore the physics options present by such a machine. However, I think we still have to learn more from the LHC, as well as from some precision experiments and from astrophysics as well.

PC: Do you think that maybe we should also reconsider the speculative character of science?

JB: I never believed that there is a hard divide between exploratory and theoretically driven science. I think any good large-scale project would be based on a mix of the two. We had a huge theoretical motivation with the Higgs at the LHC, but we also pursued, and still pursue, an exploratory aspect. One of my favourite plots is the charge current and neutral current cross section in Deep Inelastic Scatter from HERA. You could see the weak and electromagnetic forces coming together around 100 GeV — that is a real change in high energy physics that we knew that the LHC could probe. This is motivated partly by theory and partly by experiment.

The bigger and longer-term a project is, the stronger its motivation has to be. For a small project you can take a long-shot and come up with a high-reward, high-risk plan. There is, however, a trade-off between doing a large number of these experiments and constructing a large accelerator, since resources, including physicists who can work on such projects, are not infinite. This balance of large and small experiments should be examined case by case given also the long lead times for these projects.

Finally, one should bear in mind that we live in a kind of ecosystem in which is important to advance our R&D efforts for new technologies. New developments have a strong impact, even if not directly applied to fundamental physics, including the development of new accelerators, high-field magnets and fast computing needed to process data from future detectors.

PC: Do you think that nowadays there is a strong complementarity between research in HEP and in astrophysics?

JB: I am chair of a department that is home to a very strong astrophysics and cosmology group. I found their combination of theoretical motivation and exploratory driven science very interesting. Much of astronomy is pure exploration — going to Pluto is not about fundamental physics but about investigating the solar system. Of course, studying cosmology and trying to understand dark matter or dark energy and how the Universe evolved is closely linked to the fundamental questions that particle physics tries to answer. Some of our undergraduate students found an exoplanet, and another group found a supernova. I slightly envy them. It might not be a fundamental breakthrough in the theory of supernovae but they discovered something new, that lies out there.

PC: Finally, I would like to discuss your motivation to communicate science and what is the personal reward.

JB: I have always enjoyed writing something other than a scientific paper. As a field, being able to explain our work to a non-scientific audience is just as important as publishing in peer-reviewed journals, in my opinion – though not everyone has to do both! We live in a complex society and people often cannot understand and differentiate between fiction and fact. As our lives are heavily based on science and technology, we need scientists to engage with society and discuss their work with the people. Not to mention that it can be very fun as well.

john butterworth UCL science communication smashing physics Higgs Boson issue 19

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Cryogenic safety tool developed at CERN

by Jennifer Toes (CERN)

Participants of the Cryogenic Safety - HSE Seminar at CERN, September 2016 (Image: Julien Ordan, CERN)

In September 2016 CERN hosted its first seminar on cryogenic safety and attracted 120 participants. The seminar was organised by CERN's occupational Health Safety and Environmental (HSE) Protection Unit, and built upon their expert knowledge on cryogenics, as a result of the extensive cooling systems in place for the Large Hadron Collider (LHC).

The seminar aimed to bring together research institutes and members of industry on topics such as European activities and standards, research and development, risk assessment, and the development of rules and regulations for cryogenic safety systems.

As part of their work, CERN's HSE unit spear-headed the development of a pioneering tool,

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named Kryolize Professional, to help size the safety devices used in the LHC cryogenics systems. Kryolize allows engineers to correctly calculate the sizing requirements of cryogenic pressure relief devices, which is crucial in minimising the risk of overpressure.

Whilst originally created for internal use by LHC engineers, Kryolize Professional can also be applied outside of CERN and High Energy Physics (HEP) research. The tool was developed within the scope of international, European and American safety standards to create a harmonised approach across different fields, such as in the food industry or for medical applications.

Standards exist for some industries and applications, but they are not always standardised across disciplines.

"When we go to very low cryogenic temperatures, like we use at CERN, these standards do not exist or they're not fully tailored," said Andre Henriques, a Mechanical Engineer and Kryolize project leader.

The CERN Knowledge Transfer (KT) group has supported the Kryolize project to facilitate its dissemination beyond CERN, In particular by granting it funding through the CERN Knowledge Transfer Fund.

The next steps are to verify the tool's parameters, harmonize its data, develop and finalise its user interface, obtain commercial licences and disseminate the software abroad and throughout different disciplines.

In addition, the project will participate in standardisation committees across Europe to ensure harmonized and tailored approach in cryogenic safety.

"Safety should be the front wagon in the development of new technology," said Henriques.

Further reading:

- Kryolize project video: https://cds.cern.ch/record/2220439
- Read more about Kryolize on the CERN Knowledge Transfer website.
- For more information on obtaining a licence for Kryolize, please contact the CERN Knowledge Transfer group.

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Carlos Moedas on the importance of SESAME as a model for science diplomacy

by Livia Lapadatescu (CERN)

EU Commissioner for Research, Science and Innovation, Carlos Moedas, during his visit to SESAME in Jordan, April 2015. (Image credit: 2015-2016 CERN)

At the 28^{th} SESAME Council held in May 2016 in the premises of the European Commission, the EU Commissioner for Research, Science and Innovation, Carlos Moedas, gave an introductory talk on SESAME as an example of cooperation in the Middle East through science diplomacy.

SESAME, as a model of scientific cooperation in the Middle East, is part of the European Union priority to ensure that European Research and Innovation are "Open to the World" and was an inspiration for the book on *Open Innovation, Open Science, Open to the World – a* *vision for Europe*, published by DG Research and Innovation in May 2016. Science diplomacy has been one of the priorities of Commissioner Moedas and three science diplomacy pillars have been set up: **(i) building bridges and improving international relations**; **(ii) addressing global challenges through sound scientific advice**; **(iii) embracing globalization through enhanced STI cooperation**. For example, Carlos Moedas gave the initiative of FP7 CESSAMag project as an example and a trigger, and his visit to CERN and the CESSAMag laboratory in January 2015 was the beginning of the first pillar with SESAME bridging divides in the Middle East.

In the framework of this first pillar historical agreements were signed associating some countries to Horizon 2020, such as Ukraine and Tunisia in 2015 and Armenia and Georgia in 2016. Another example of a bridge-building activity is the PRIMA initiative (Partnership for Research and Innovation in the Mediterranean Area), a cooperation in the Mediterranean region, bringing neighbours at odds together, on how to ensure the sustainable provision of vital resources such as water and food.

In the context of the second pillar, a high-level group of seven scientific experts for scientific advice on specific policy issues in Europe was set up. In addition, a Science4Refugees programme was launched to help refugees with a science background find suitable jobs in universities and research institutions in the EU.

With respect to the third pillar, progress has been made towards the creation of a Global Research Area based on the development of a Common Research Area for the EU, Latin America, and the Caribbean. This has been manifested by the decision of the 28 EU member states to make scientific papers freely available by 2020 or the setting-up co-funding mechanisms with China and Mexico.

To conclude, the EC Commissioner, informed participants that €2M had been earmarked for SESAME in the 2016-2017 Horizon 2020 Work Programme and stressed the fact that he has become emotionally involved in this project and would continue to be the SESAME Ambassador and an advocate on scientific cooperation in the Middle East through SESAME.

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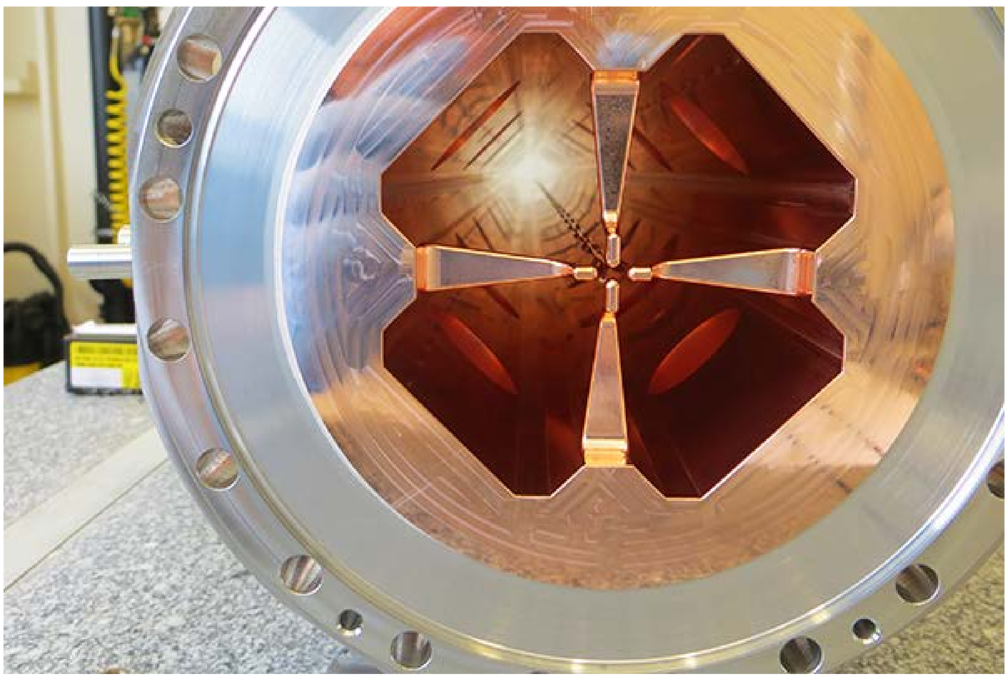
A revolutionary mini-accelerator

by Panos Charitos (CERN)



A glimpse in the accelerator structures of the world's smallest accelerator (Credit: CERN)

CERN is the home of the 27-kilometre Large Hadron Collider (LHC) that searches for new discoveries by colliding protons at extraordinarily high energies. The unprecedented energy levels led to the discovery of the Higgs boson, the last missing piece in the Standard Model, and now open a new chapter in fundamental physics. The development of such complex machines is based on the advancement of novel technologies and invaluable know-how, which can be capitalised in other fields outside particle physics.

Sometimes working for the largest accelerators gives ideas on how to build the smallest ones; the construction of the world's smallest Radio Frequency Quadrupole (RFQ) for proton acceleration that was completed in September provides one of the most successful examples. This miniature machine is a linear accelerator (linac) consisting of four sections of only 130 mm diameter, operating at a frequency of 750 MHz, for a total length of 2 metres. It can accelerate low-intensity proton beams of a few hundreds of microA up to the energy of 5 MeV.

It should be noted that the mini RFQ cannot be used for the large colliders needed for fundamental research, since it cannot achieve high peak currents. The small size and low current is however what makes this design ideal for a wide range of medical and industrial applications.

Maurizio Vretenar (CERN), head of the LINAC4 project and coordinator of the design and construction of the mini accelerator, said: “The challenge to develop this miniature accelerator came from a spin-off company that aims to take advantage of the knowledge and infrastructure of CERN in building new accelerators. The main idea was that a mini-RFQ is a much more efficient injector than a cyclotron to a compact proton linac for particle therapy. The linac-based facility under development will permit a more precise 3D scanning of tumours than what is possible with other proton therapy machines or conventional radiotherapy.”

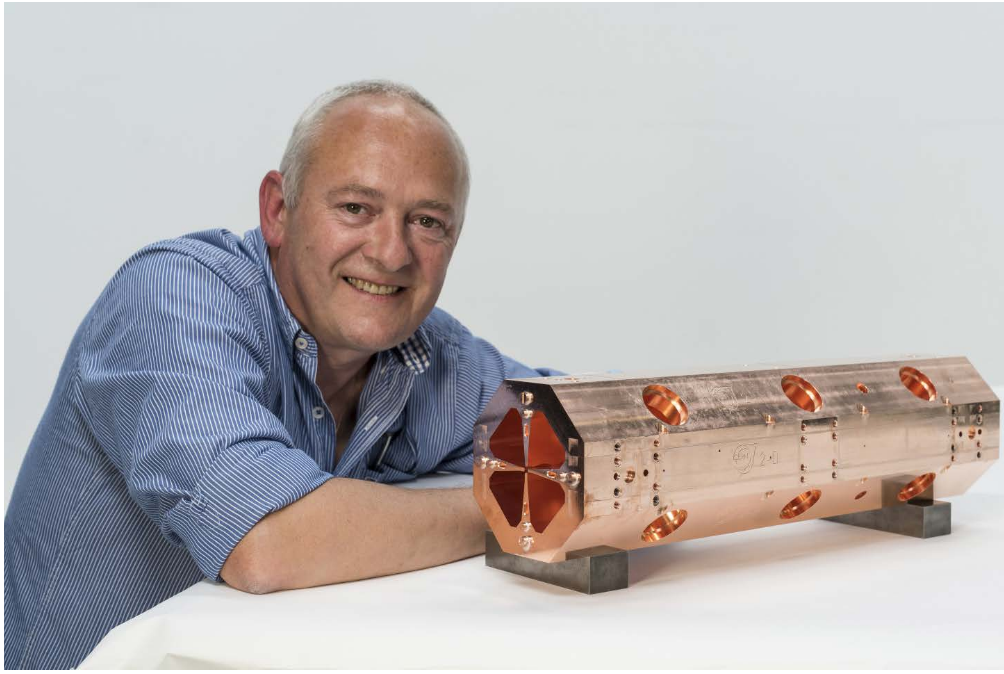
Vretenar explained: “Reaching high frequencies is particularly challenging, but it is the only way to build compact accelerators. For proton linacs at CERN, we started with the 200 MHz LINAC2 at the end of the 1970s and since then we have almost doubled the frequency to 350 MHz for the recently commissioned LINAC4. With the new LINAC4 we will be able to double the beam intensity in the LHC injectors, thus significantly contributing to an increase of the LHC luminosity,” and continues: “the idea of constructing a smaller accelerator that could produce low-intensity beams for medical purposes has been a long-standing technological challenge. It dates back to the 1990s when it seemed almost impossible to build such a small RFQ.”

The rich experience that the CERN team has gained from the design and development of LINAC4 made a new miniature RFQ accelerator seem more plausible. The main challenge was to double the operating frequency, resulting in more accelerating cells and a shorter length, but at the same time leading to a very challenging beam optics design and RF resonator. With the high frequency RFQ, we have more than doubled the accelerating capabilities (2.5 MeV/metre in place of 1 for the LINAC4 RFQ) and reduced by a factor 2 the construction cost per metre.

The way to the higher frequencies was opened by a new beam dynamics approach developed by Alessandra Lombardi, who now follows the testing and commissioning of the RFQ in ADAM’s premises. The next challenges to address were the tuning of RFQs that are long with respect to the wavelength and the machining and brazing of RFQ parts of unprecedented small size.

The design and construction of the RFQ relied on a sophisticated mechanical approach defined by Serge Mathot and on a detailed definition of the resonator properties and tuning strategy by Alexej Grudiev (BE).

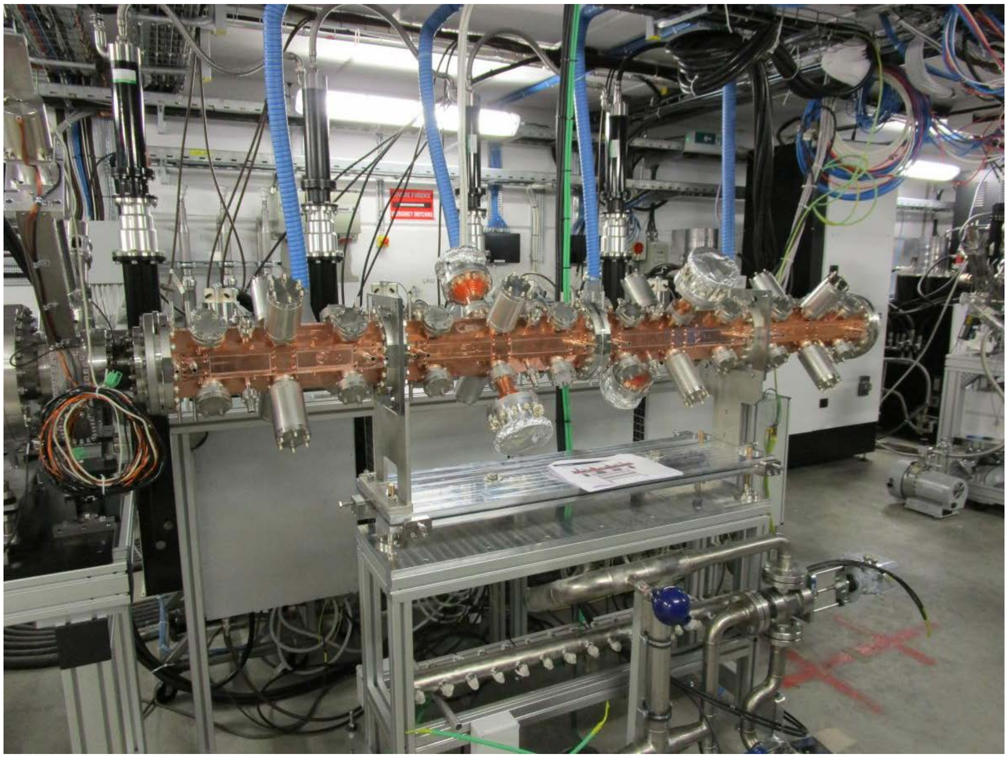
Thanks to the collaborative spirit and the passionate work of CERN’s people who worked in this project, the team recently completed the brand-new mini accelerator. The four modules that make up the final accelerator have been entirely constructed in CERN's workshops within less than two years through the effort of a small but enthusiastic team. The fact that what they were building could help treating thousands of patients gave extra motivation to everyone involved in the project. In addition, Serge Mathot explains: “the construction was a very delicate procedure, given the need for high precision and the geometry of each module. Thanks to the experience and the skills we have gained from our previous works on the cavities for LINAC4, we successfully met the challenges of this project”.



Serge Mathot in front of one of the four modules (Credit: CERN)

The technological breakthrough achieved by the team behind the mini-accelerator has attracted interest from the industry, in first instance from A.D.A.M. SA, which stands for Applications of Detectors and Accelerators to Mediciane, a Geneva-based spin-off company from CERN, and from its parent company Advanced Oncotherapy in the United Kingdom. "Behind every innovative aspect of this accelerator, there is unique CERN intellectual property and know-how", says David Mazur from CERN's Knowledge Transfer Group, "and we have concluded a license agreement with A.D.A.M. SA which enables them to commercialize such accelerators in the field of proton therapy, based on our IP".

The mini accelerator was delivered to the ADAM test facility last September and is presently being commissioned. It is more modular, more compact and cheaper than its “big brothers”. Its small size and light weight mean that the mini-RFQ could become the key element of proton therapy systems but also of systems able to produce radioactive isotopes on-site in hospitals.



The mini accelerator (RFQ) installed in the ADAM test stand (Credit: ADAM)

The team that developed the mini-RFQ foresees many other potential medical applications, such as acceleration of alpha particles for advanced radiotherapy techniques that may be the new frontier in the treatment of cancer or industrial applications, where a mini accelerator could analyse the quality of surfaces or trace aerosol pollution for example.

Also, the small size of the new accelerator means that it can be easily transported, which would be particularly useful for the surface analysis of archaeological materials or artworks presently exhibited in museums around the world, using proton-induced x-ray emission (PIXE) analytical technique. Indeed a new generation of mini accelerators have great potential and could find numerous applications in many fields. The mini-RFQ offers another example of the societal benefits stemming from fundamental research.

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New collaboration board for HL-LHC

by Isabel Bejar Alonso (CERN) and Panos Charitos (CERN)

The HL-LHC Collaboration Board [HLCB] is the official forum for information exchange and dialogue between the HL-LHC collaborators, HL-LHC project management and CERN management (Image: CERN)

The first session of the new HL-LHC Collaboration Board took place in Paris on 14th November 2016. The HL-LHC project moves from its initial conceptual design phase into the constructive design phase, which marks the beginning of construction for some HL-LHC components.

Moving into the new phase is reflected not only by the change of the composition of the Collaboration Board, but also in the relations with the institutions working for the HL-LHC.

Lucio Rossi, HL-LHC Project Leader points to the increasing number of Member States that contribute through their universities and research centres. Finland, Poland and Sweden have joined, in addition to a strengthened relationship with the States which were already part of the design study, such as France, Italy, Spain and the United Kingdom.

“We are particularly proud of the UK contribution, where not only the number of universities is increasing, but also the domains of competence,” notes Lucio Rossi, HL-LHC Project Leader.

Contributions to HL-LHC are also not limited to Europe. Canada is represented by Triumf laboratory, which is also a new member of the Collaboration Board. The SLAC National Accelerator Laboratory, located in California, joins BNL, LBNL, Fermilab and Old Dominion University (Virginia) in the effort of US contribution. In addition, Asia is represented in the collaboration by Japan, while China may soon join the collaboration.

A new general framework contract based on a multi-party memorandum of understanding (MoU) that allows a more flexible exchange of personnel between partners has been agreed upon. Additional contributions can be added by the laboratories via simple addenda.

Collaboration partners include laboratories and institutes who have either signed directly a HL-LHC collaboration agreement or are part of an overreaching general collaboration agreement, will provide either significant in-kind contributions or studies and personnel for the HL-LHC project.

Institutes that have signed the MoU but do not provide an explicit in-kind contribution to HL-LHC are to be considered observers.

The present HL-LHC Collaboration Board has 21 members and 10 observers and is chaired for the next two years by Robert Appleby from the University of Manchester in the UK.

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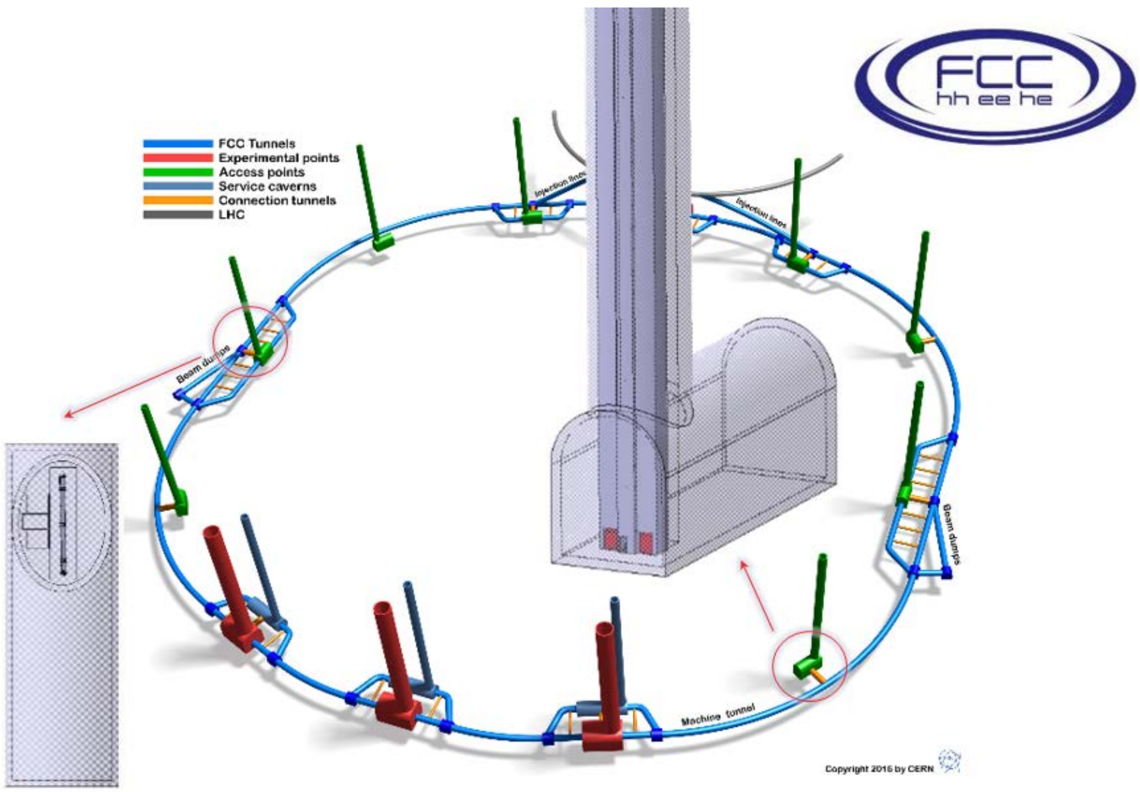
Designing an elevator system for FCC

by Panos Charitos (CERN)



Designing an elevator system for a 300 underground tunnel that could host a future circular collider (Image: CERN - FCC Collaboration)

CERN has come a long way since its foundation in 1954 in advancing our knowledge about the basic components of the Universe. This was made possible due to the advancements in technologies and the building of more complex accelerators and detectors that significantly push the limit of our knowledge. This complexity calls for long-term planning of any future development.

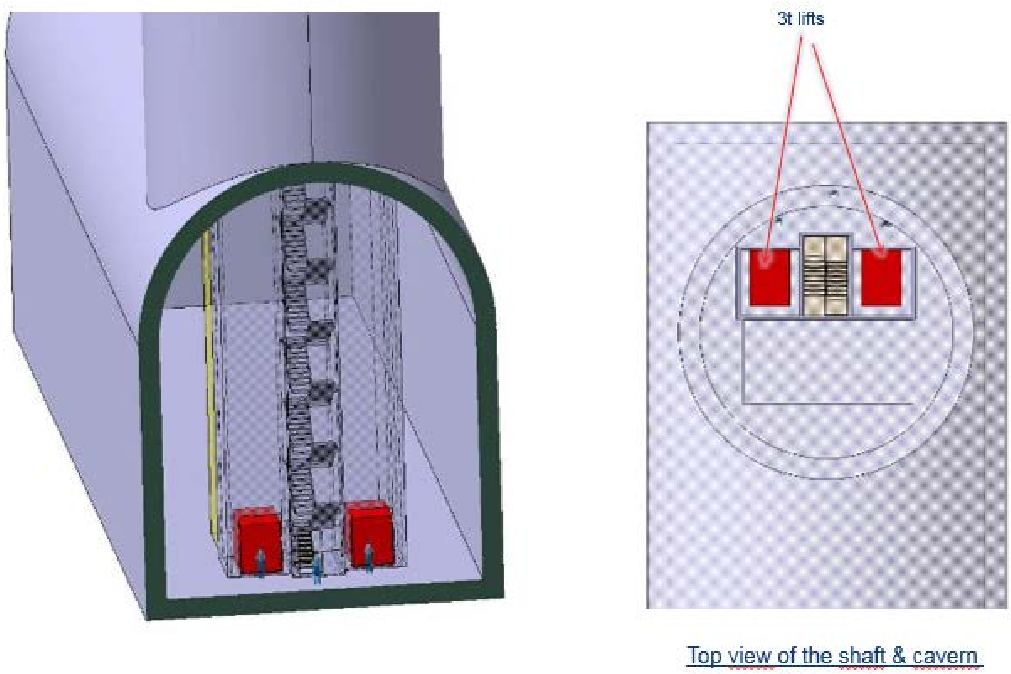
Building a larger and more powerful accelerator sets a number of challenges related to physics and accelerator parameters but also to civil engineering and day-to-day operations. A future collider like those explored under the FCC study will not merely be a scaled-up version of the LHC but a totally new machine. Scientists and engineers are working to develop new technologies and concepts for building and running such a large-scale research infrastructure.

Designing a 100 km tunnel, lying in an average depth of 300 meters that could host a future collider and the experimental detectors is not a trivial task.

First of all, one needs to face open issues related to the installation of the different accelerator parts, including the high-field magnets, the commissioning of the detectors and the need to transfer equipment between the tunnel and surface facilities. There are many more questions when designing such a system like: "How many people will move within such a large underground facility? How often they will need to access the tunnel and from which points? How quickly will the tunnel be evacuated to ensure safety for the personnel?

Volker Mertens, who is in charge of the Infrastructure and Operation studies for the FCC study, notes: "answering these questions becomes more challenging as the answers depend on the available state-of-the-art technologies and a possible project on how they could evolve within the next 20 years."

A key aspect of the construction and operation phase linked to the above questions is the elevator system that will be installed. Engineers are working to design a number of elevators that will efficiently connect the tunnel with the surface giving access to the engineers and technicians that will work in this project. Damien Lafarge, section leader at CERN responsible for lift operation explains: "lifts that give access to underground part are one of the most vital parts in designing a post-LHC collider. They must be operational all time, with an availability rate of 99.6% as any failure can be very costly in the operation of such a large-scale infrastructure".



An overview of the cavern and the elevator system (Image: CERN - FCC Collaboration)

At this early stage engineers are looking nominally at 12 deep access shafts, where approximately 24 lifts could be located at significant locations intervals along the collider ring. Volker notes that: "to ensure quick and successful intervention in the tunnel, the number of shafts around the tunnel, the number of lifts in each shaft and their capacity are key elements". Presently at the LHC sixteen elevators are used to connect the surface to the LHC and its experiments. The one-stop ride between the surface and the tunnel last about one minute while the cabins of these lifts can carry loads from 1 to 3 tons up to a speed of 2.5 m/s.

For FCC a slightly higher speed of 4-6 m/s to keep the duration of the ride to two minutes and a similar load of 3 tons are discussed as baseline parameters. However the greater depth of the tunnel means that one needs larger cables and thus the total weight of the cables becomes a critical issue. In fact, it turns out that the cables weigh much more than the actual cabin load as Lafarge explains. To address this issue we discuss with our industrial partners different scenarios; from using different materials to a more clever design for the elevator system.

The LHC lifts have made nearly 9'140'000 races ranging from 45.35 to 143.54m, over the LEP and LHC run 1 operation periods. You can multiply this by a factor of 2 or 3 based on the depth and number of components of a future collider (3 times bigger than the LHC) to get a rough idea of the wear and tear that the elevator system will be exposed to. That's why a key idea is now to get a redundancy with 2 lifts per shaft in order to reduce constraints on each lift, therefore maintenance costs, and increase the reliability of the function "access to the underground" at the same time!

Ingo Ruehl, an expert in CERN's Handling Engineering (HE) Group comments: "the earliest stages of any construction project offer the most opportunity for maximising quality and reducing total project costs. With this in mind, we are working in partnership with world leading engineering consultancies to utilise the latest methods and technology to ensure the best possible outcome from the first stages of design."

Thinking and designing the next generation of elevators that will be used for FCC, reliability and availability are realized to be key factors in future large and high-performance colliders as they can guarantee an efficient operation. CERN is working closely with its industrial partners to explore the latest generation of monitoring system for elevators, allowing to anticipate failures, an essential element to ensure the reliability of our facilities.

In the next years, a detailed presentation of the available technical options for the elevator system of the FCC will be prepared. This will be included in the FCC conceptual design report that will cover every aspect of building and operating such a future large-scale infrastructure. FCC offers a unique opportunity for experts in elevator engineering to think of novel solutions in order to address the unprecedented challenges posed by such a large underground facility.

Designing an efficient elevator is important to guarantee the safety for the people installing, maintaining and operating a future more powerful collider and running new experiments that will allow to go deeper in our understanding of our Universe!

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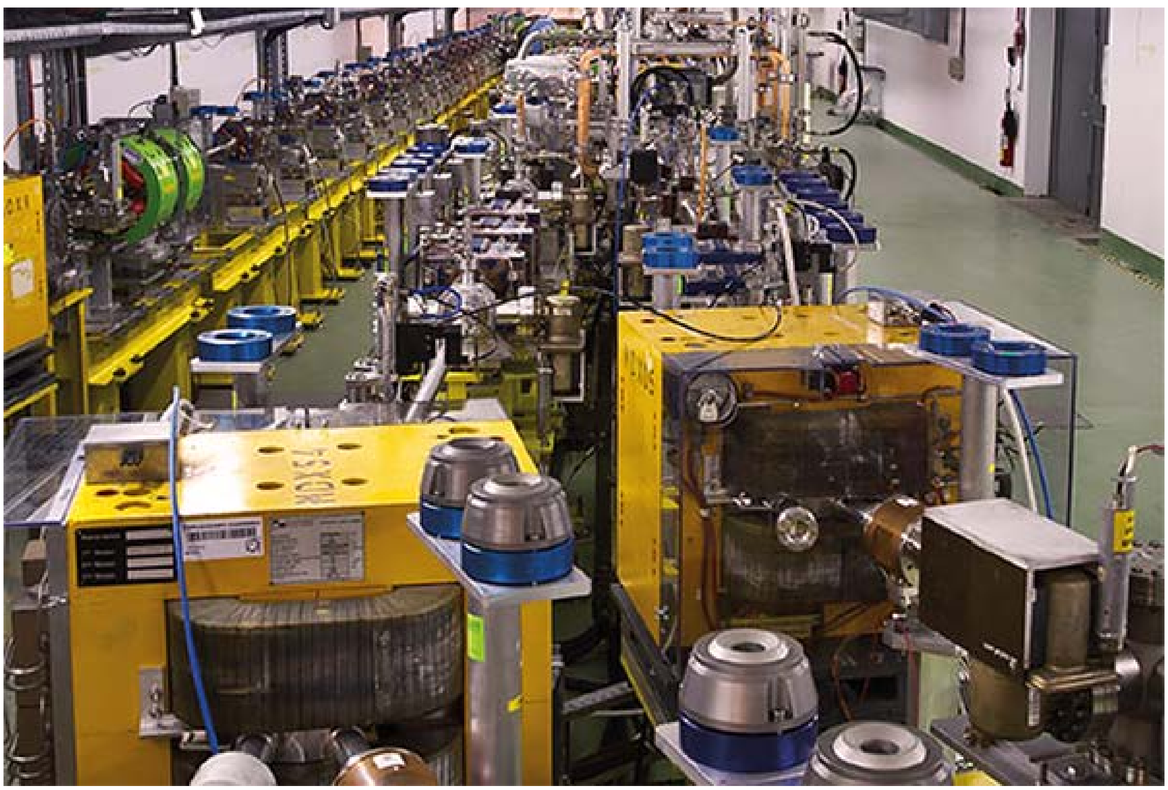
Optimized first energy stage for CLIC at 380 GeV

by Daniel Schulte & Philipp Roloff (CERN)



The CTF3 test facility at CERN, which has demonstrated CLIC's novel two-beam acceleration technology (Image credit: Maximilien Brice)

In the post-LHC era, one of CERN's potential options for the next flagship accelerator is an electron–positron collider at the high-energy frontier; the Compact Linear Collider (CLIC).

In August 2016 the CLIC collaboration, which consists of 75 institutes, published an updated baseline scenario. This scenario starts with a first energy stage at 380 GeV center-of-mass, followed by a second stage with an energy around 1.5 TeV, and a final step to 3 TeV.

Prior to the discovery of the Higgs boson particle, the CLIC conceptual design report (CDR)

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focused on the design of the 3 TeV stage and has documented the viability of the technology required for this energy. Lower energy stages have been considered with much less detail.

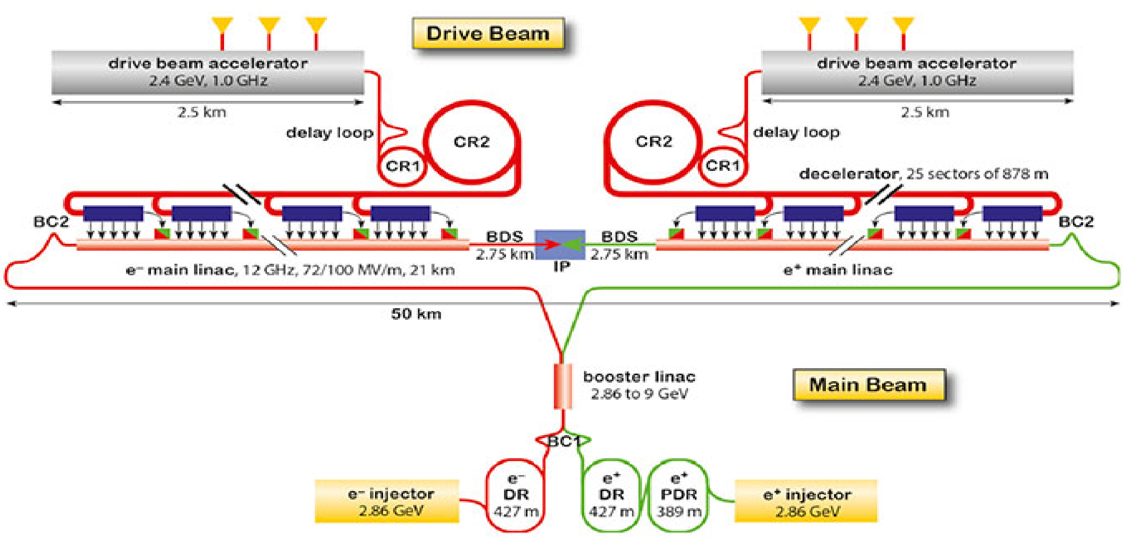
With the information obtained from the Higgs discovery, the optimum energy choice for the first stage was also studied. The physics programme has been evaluated, including detailed studies of realistic detector configurations. The choice of 380GeV would allow detailed measurements of the Higgs boson and the top quark.

To optimize the CLIC accelerator, a systematic design approach has been developed and used to explore a large range of configurations for the RF structures of the main linac. For each structure design, the luminosity performance, power consumption and total cost of the CLIC complex are calculated.

For the first stage, different accelerating structures operating at a somewhat lower accelerating gradient of 72 MV/m will be used to reach the luminosity goal. The design of this will have a cost and power consumption similar to earlier projects at CERN such as LHC with its injectors, whilst it ensures that the cost of the higher-energy stages is not inflated. The design should also be flexible enough to take advantage of projected improvements in RF technology during the construction and operation of the first stage.

In order to upgrade to higher energies, the structures optimized for 380 GeV will be moved to the beginning of the new linear accelerator and the remaining space filled with structures optimized for 3 TeV operation. The RF pulse length of 244 ns is kept the same at all stages to avoid major modifications to the drive-beam generation scheme.

Data taking at the three energy stages is foreseen to last for a period of seven, five and six years, respectively. The stages are interrupted by two upgrade periods of two years, meaning that the overall three-stage CLIC programme would last for 22 years from the start of operation. The duration of each stage is derived from integrated luminosity targets of 500 fb^{-1} at 380 GeV, 1.5 ab^{-1} at 1.5 TeV and 3 ab^{-1} at 3 TeV.



Overview of the CLIC layout at 3 TeV, showing combiner rings (CR), delay loop, damping ring (DR), pre-

damping ring (PDR), bunch compressor (BC) and beam delivery system (BDS). The red and green squares represent beam dumps. (Image Credit: CLIC collaboration).

Further improvements are being pursued via an intense R&D programme. For instance, the CLIC study recently proposed a novel design for klystrons that could increase efficiency significantly. In addition, permanent magnets are also being developed that are tunable enough to replace the normal conducting magnets are also being developed as they could reduce power consumption even further.

The goal is to develop a detailed design of both the accelerator and detector in time for the update of the European Strategy for Particle Physics towards the end of the decade.

***A version of this article appeared in the November 2016 issue of CERN Courier.**

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Acc

Triplet magnets program progressing on both sides of the Atlantic

by G. Ambrosio, P. Ferracin, E. Todesco (CERN)

The Nb_3Sn 150 mm aperture quadrupoles MQXF, to be installed in the inner triplets around ATLAS and CMS in 2024-5, are entering a critical phase; the first two 1.5-m-long models have been manufactured and tested since the beginning of this year.

This magnet development program, carried out as a joint effort between CERN and US LARP foresees the construction and testing of five 1.5-m-long models to validate the design and fine tune the assembly features during 2014-17.

These magnets rely on the Al shell and bladder&key structure, allowing easy and fast disassembly, and a precise tuning of the coil prestress. Mechanics is a critical part in the design of these large aperture quadrupoles, featuring an 11.4 T peak field in the coils (50% larger than the peak field in the LHC dipoles operating at 6.5 TeV).

The first model, MQXFS1, was assembled in the U.S. with two CERN coils and two LARP coils, and was confirmed to fulfil performance requirements in April 2016 (see Figure 1). The performance requirements included a) reaching the ultimate current (8% higher than the nominal current of 16.4 kA), and b) reaching nominal current after a thermal cycle with at most one quench.

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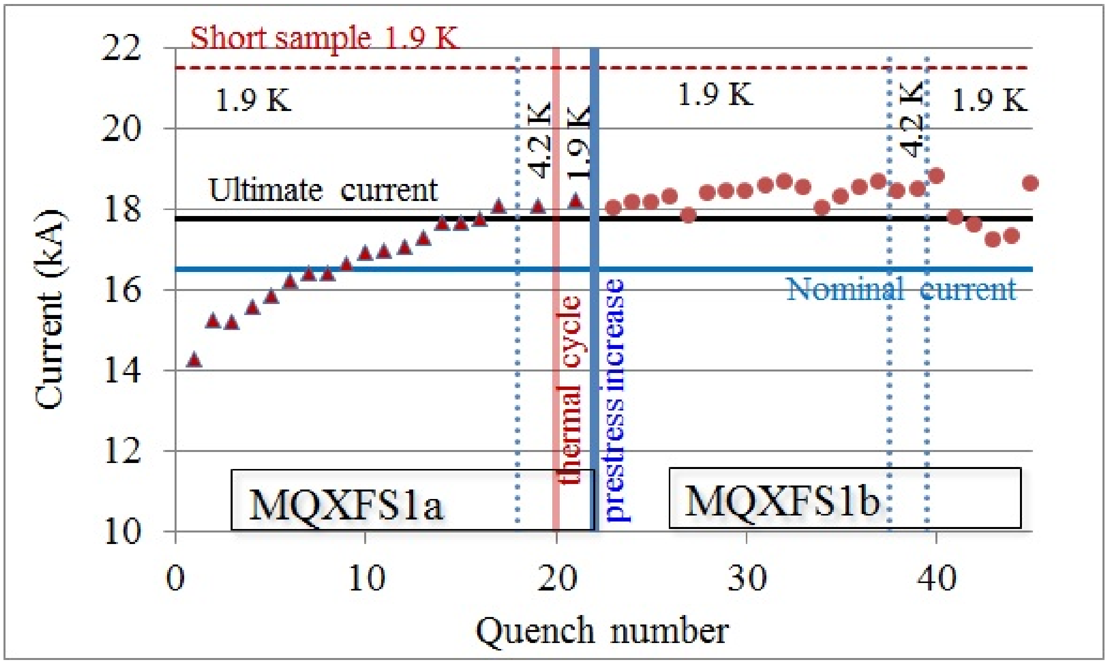


Figure 1: Training of MQXFS1: quenches (markers), nominal and ultime current (solid lines) and short sample limit (dotted line). (Credit: HL-LHC WP3 collaboration)

The memory after thermal cycle has outperformed expectations by exceeding ultimate current in the first quench after the thermal cycle. However, training has been slower than expected, reaching nominal current after nine quenches. After this first cycle of testing, the transverse pre-stress in the magnet was increased by 30%, to ensure a better support to the coils.

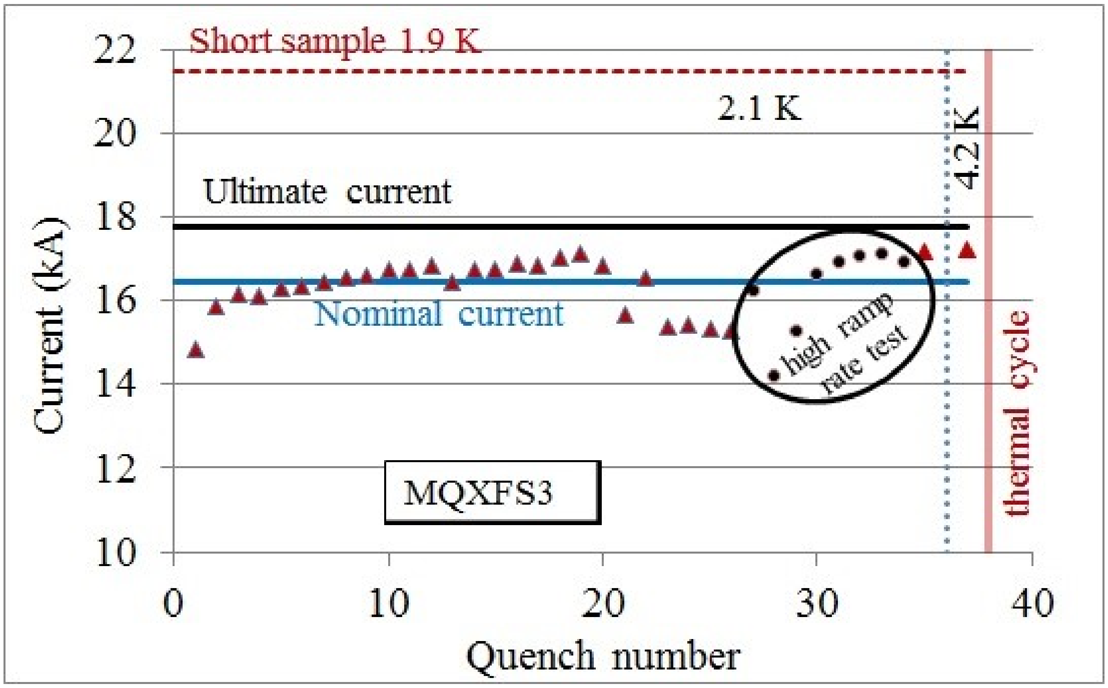
In October 2016, the second assembly was tested at FNAL, reaching 18.8 kA; which is 15% more than the nominal current, and close to 90% of the maximum theoretical performance of the magnet. Some detraining has been observed sporadically, reducing the magnet performance but keeping it always well above the nominal current.

At 4.2 K the magnets shows the ability to reach the same current, thus demonstrating the existence of a considerable margin in temperature, meaning the magnet should tolerate local heating).

The second model, MQXFS3, (MQXFS2 has been postponed to 2017) has been tested at CERN in October 2016, using a novel test station (HFM) planned to be used for the Fresca II dipole.

The magnet reached nominal current with nine quenches, as MQXFS1, but reached a current only 4% above nominal after 20 quenches. A significantly larger detraining than in MQXFS1 was observed, pushing the magnet performance well below nominal (15.0 kA).

Nonetheless, the maximal performance of 17.2 kA has been recovered after ramp rate tests. In addition, 4.2 K test, shows the same performance reached at 2.1 K and also demonstrates the existence of a considerable temperature margin.



Training of MQXFS3: quenches (markers), nominal and ultimate current (solid lines) and short sample limit (dotted line). (Credit: HL-LHC WP3 collaboration)

Work is now focussed on understanding the relationship between the quenches and the mechanical structure. As quenches are mainly located in the coil heads the longitudinal preload will be increased. Further testing after the thermal cycle is expected for the end of the year and . three additional models are foreseen in 2017.

The program will run in parallel with the development of the long coils (4.2 m in US and 7.15 m in CERN) required for the full size magnets.

“The short model program is a fundamental tool to master the design and construction of superconducting magnets, and it is even more important for a novel technology as Nb3Sn” says L. Bottura, leader of the CERN Magnet, Superconductors and Cryostat group. “If needed, we will prolong the short model program to improve our understanding and to reduce the risks in the construction of the prototypes and of the series.”

MQXFS magnets quarupoles HiLumi NB2Sn ATLAS CMS CERN US-LARP issue 19

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eeFACT2016 held in Daresbury UK

by Ralph Aβmann (DESY), Peter Ratoff (Cockcroft Institute) and Frank Zimmermann (CERN)

eeFACT2016: Participants of eeFACT2016 on the Daresbury campus (Image: Cockcroft Institute)

From 24 to 27 October 2016, accelerator experts from around the world gathered in Daresbury, UK, to discuss the state of the art, the challenges and the future directions for circular high-luminosity electron-positron factories.

The eeFACT2016 workshop was organized under the umbrella of ICFA and co-sponsored by the EuCARD-2 "Extreme Beams" accelerator network. An international committee co-chaired by Yoshihiro Funakoshi from KEK, Qing Qin from IHEP, and Frank Zimmermann from CERN had assembled a programme reflecting the breadth of the ongoing worldwide efforts.

The Cockcroft Institute, with the hospitality of its Director Peter Ratoff and the outstanding support from Liz Kennedy and Sue Waller, proved a perfect host for this event. Participants hailing from China, Italy, Japan, Russia and the United States appreciated the smooth organization, wonderful venue, plus the chance to visit nearby historical Chester. The timing of the workshop could not have been better, including for the weather: during all four days the sun was shining, in what seemed like a British Indian summer.

Circular colliders have been a frontier technology of particle physics for half a century, with more than a factor 10 luminosity increase every ten years. Several lower-energy factories are in operation, continually improving their performance: BEPC-II at IHEP Beijing, DAΦNE at INFN Frascati, and VEPP-2000 at BINP Novosibirsk.

The Super-B-factory SuperKEKB, presently under commissioning in Japan, will be the next big upward step in luminosity. Among other future projects, a Super-charm-tau factory is being developed in Russia, while two ambitious highest-energy circular Higgs-Z-W (and top) factories are under design: the Circular Electron Positron Collider (CEPC) in China, and the electron-positron version of the Future Circular Collider (FCC-ee) on the Franco-Swiss border.

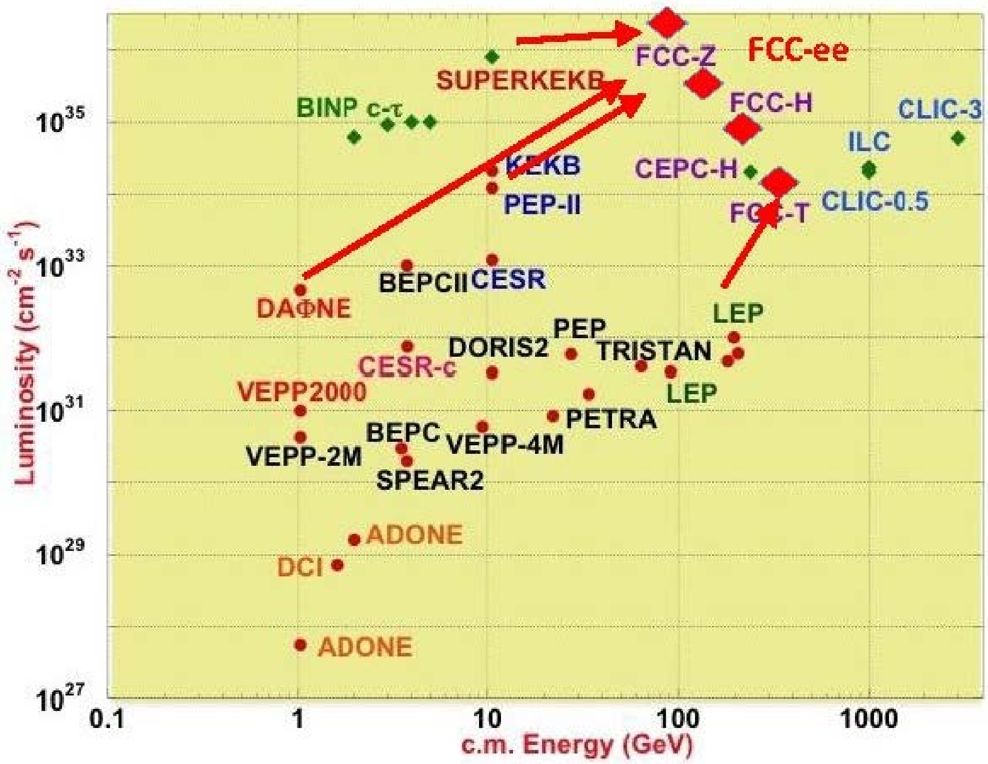
At eeFACT2016, DESY leading scientist Ralph Assmann recognized the continuing high level of innovation, even after an already 50-year long history of colliders, and a wealth of novel concepts. Over the last couple of years, several game-changing schemes have been introduced, for example colliding beams with a crab waist, large Piwinski angle and extremely low emittance.

The crab-waist concept was presented by its inventor Pantaleo Raimondi, now Director of the Accelerator and Source Division at the ESRF. This crab-waist scheme has already demonstrated its great merits in actual beam operation at DAΦNE. Other novel concepts include the use of a double ring or partial double ring, magnet tapering for the energy sawtooth, top-up injection, cost-effective 2-in-1 magnets, ultra-low beta function, "virtual crab waist" and asymmetric interaction-region optics.

The last two concepts were rather recently developed by Katsunobu Oide, former Director of KEK's Accelerator Laboratory. Upcoming colliders like SuperKEKB will test the limits of these new schemes and manifest their positive impact. The upgraded VEPP-2000 collider will push the concept of round beams. In parallel much progress is being made in the design and operation of storage-ring light sources. An excellent review by ESRF's world expert Dieter Einfeld revealed numerous topics of common interest with the collider world. Lastly, not to be forgotten is the built-in synergy of a future large circular high-energy lepton collider, such as CEPC or FCC-ee, with a subsequent hadron collider installed in the same tunnel, called SPPC and FCC-hh, respectively – as was highlighted by Alain Blondel from the University of Geneva.

The projected performance of the future factories is further lifted by a dramatic progress in accelerator technology. An entire session, convened by JLAB's Bob Rimmer, was devoted to the radiofrequency (RF) system, which, working in continuous wave mode, needs to transmit a large power and support high beam currents at a high efficiency.

An essential component of this system is superconducting RF (SRF) cavities, whose overall efficiency is revolutionized by novel production schemes such as nitrogen doping and thin-film Nb3Sn coating. Several novel klystron concepts are on track to boost the power conversion efficiency of RF power generators. Thanks to this type of innovation, when compared with previous colliders the next generation can be considered truly green facilities.



The luminosity-energy plane of past, present and proposed future e+e- colliders. Combining successful ingredients of recent colliders and adding further innovative concepts promises extremely high luminosities at energies ranging from the Z pole to the tt threshold as illustrated by the plotting symbols for FCC-ee and CEPC (Image: Marica Biagini and Frank Zimmermann).

Alex Chao, an eminent physicist from SLAC, summarized that with performance being pushed so hard at the future factories, more subtleties that were unimportant in the past now arise. Indeed new effects keep being discovered for the beam-beam effects, such as the requirement of crab waist, residual nonlinearities after the crab waist cancellation, beamstrahlung, 3D flip-flop instability, interplay with lattice nonlinearities, and the possible interplay with collective effects. Alex Chao underlined that the beam-beam issue will become more critical than ever.

The large future collider concepts FCC-ee and CEPC build upon the recent innovations and are planning to exploit their full potential at the precision frontier, measuring the properties, couplings and decays of the Higgs and several other high energy particles with extreme accuracy. New ideas for compact low-energy crab-waist colliders, possibly based at universities, are emerging as well and these might offer attractive alternative paths for research and science.

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LINAC4 reaches target energy of 160 MeV

by Jennifer Toes & Maurizio Vretenar (CERN)

Installation of the CCDTL structures of LINAC4, built and assembled in Russia (Image: CERN CDS)

CERN's new linear accelerator (LINAC4) reached its final energy goal of 160 MeV in October 2016. The new LINAC4 will double the brightness of the beam in the PS Booster (PSB), by injecting H- beams at a higher energy than the present 50 MeV of LINAC2. This is the first step for the increase of the LHC luminosity that will be possible after completion of the LIU (LHC Injectors Upgrade) and HL-LHC (High-Luminosity LHC) projects.

Approved in 2007, LINAC4 is the realization of nearly 10 years of work. The project has involved almost all CERN Departments and services, and included substantial in-kind contributions from Russia, Poland, Spain, Italy and India.

This ultimate achievement comes after reaching 107 MeV energy in July 2016. The commissioning with beam took place in stages of increasing energy; from

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3MeV in October 2013, to 12 MeV in August 2014, 50 MeV in November 2015, 100 MeV in July 2016, before ultimately bringing it up to the final goal of 160 MeV in October with the commissioning of 11 new accelerating cavities.

After optimizing the beam parameters and testing with the new high-energy beam the H- stripping equipment for the PSB, LINAC4 will begin a yearlong testing period in spring 2017. This phase will help to improve the accelerator's reliability in preparation for taking over from LINAC2 as the first element of the LHC injection chain.

The final phase will include connecting the linac to the PSB; requiring extensive modifications to both the beam lines and to the PSB itself. This will take place during the second Long Shutdown (LS2) of the CERN accelerator complex in 2019-20.

"This achievement is a great success for all the people that contributed to the project, at CERN and outside," said Maurizio Vretenar, LINAC4 Project Leader.

He continued: "All accelerating sections and components of the new linac performed remarkably well from the very beginning, showing the quality of the design, of the realisation and of the installation."

Although CERN was responsible for the construction of the LINAC4, the R&D phase which preceded it was performed in close collaboration with six other laboratories as part of the first Integrating Activity project for accelerators; CARE (Coordinated Accelerator Research in Europe), which operated from 2004 to 2008.

"The collaborative environment and the support provided by this European project allowed us to go through the critical R&D phase refining the project at the level where it can be approved for construction, and helped strengthen the collaborations that evolved into our crucial in-kind contributions," said Vretenar.

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