WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the May 2016 issue of *CERN Courier*.

The focus of this issue is "luminosity". Achieving unprecedented luminosities in the LHC is the goal of the HL-LHC upgrade project, which is featured in the Viewpoint and in one of the central articles, now that the first components are undergoing successful tests. The collision rate is crucial when looking at rare events, and past experiments know this well, as the feature about the Tevatron legacy explains. Luminosity is also a vital design parameter for any future accelerator, including the ILC featured in this issue. The News section reports on new results recently presented by the LHC experiments, including the world's most precise measurements and search for the X(5568) tetraquark candidate by LHCb. A variety of events, appointments and awards in Faces & Places complete this issue, which goes to print while the LHC is bringing beams back to collision for the continuation of Run 2.

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CERNCOURIER

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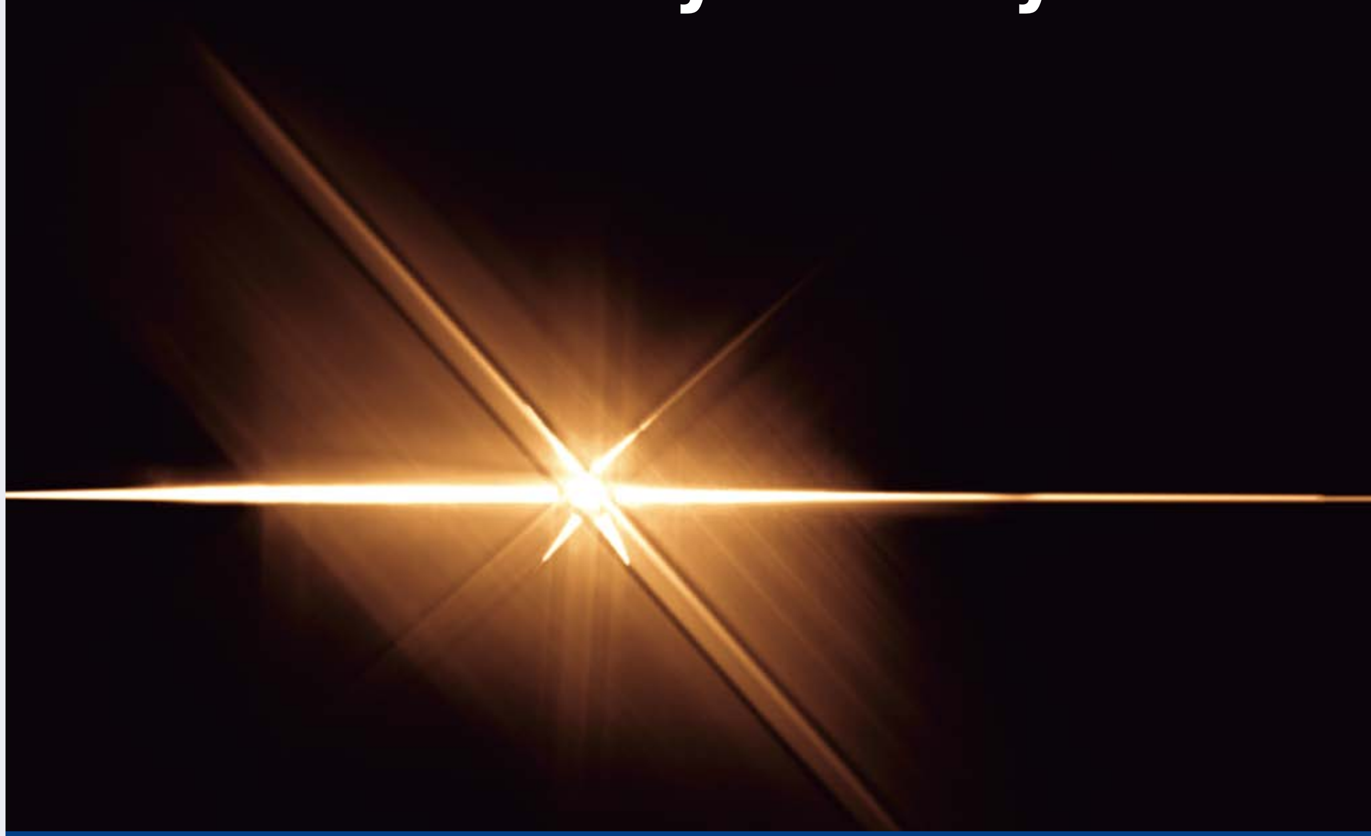
Luminosity is the key



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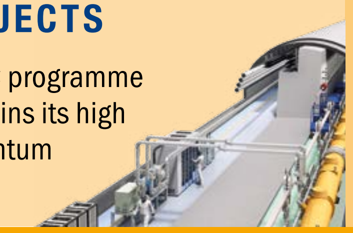

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Covering current developments in high-energy physics and related fields worldwide

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On the cover: Artist's impression of "Luminosity". For a collider, its luminosity determines the rate at which the collisions are produced. (Image credit: Symmetry Magazine.)

Viewpoint

The HL-LHC: a bright vision

Pushing the boundaries of current technology to extend the discovery potential of the LHC.


CERN

The High-Luminosity LHC project was under the spotlight during the 2015 International Year of Light.

By Lucio Rossi

The LHC is one of the world's largest and most complex scientific instruments. Its design and construction required more than 20 years of hard work and the unique expertise of a number of experts. Following on from the discovery of the Higgs boson in 2012, the machine continues to run at unprecedented energy to give physicists access to phenomena that have so far remained out of reach.

The full exploitation of the LHC and its high-luminosity upgrade programme, the High Luminosity LHC (HL-LHC), have been identified as one of Europe's highest priorities for the next decade in the European Strategy for Particle Physics (*CERN Courier* July/August 2013 p9) adopted by CERN Council in the special session held in Brussels on 30 May 2013. The HL-LHC was also recently selected as one of the 29 landmark projects of the European Strategy Forum on Research Infrastructures (ESFRI) 2016 Roadmap.

Although it concerns only about 5% of the current machine, the HL-LHC is a major upgrade programme requiring a number of key innovative technologies, each one an exceptional technological challenge that involves several institutes around the world.

At the heart of the new configuration are the powerful magnets – both dipoles and quadrupoles – that will have to operate at unprecedented field values: 11 and 12 T, respectively. In particular, the quadrupoles, also called "inner triplets", which will be installed on both sides of the collision points, are crucial components to obtain the designed leap in the integrated luminosity: from the 300 fb^{-1} of the LHC by the end of its initial run to the 3000 fb^{-1} of the HL-LHC. Their aperture will be more than double that of the current triplets – a requirement that would scare many magnet experts, because the stored energy goes with the square of the magnetic field and the magnet aperture.

The overall increase of luminosity cannot be reached without revolutionising the superconducting technologies currently used in particle accelerators. The new magnets rely on niobium-tin (Nb_3Sn) superconducting cables, instead of the LHC's niobium-titanium alloy. The first model, with full-size cross-section and shorter length than the actual magnet (1 m long compared with the final 4.2 or 7 m), has just proven that the technology works well, even beyond expectation. Similarly good results were reached in January by the experts dealing with the 11 T dipoles that will house the new collimation system for the Dispersion Suppressor, which is being entirely redesigned (see p31 in this issue).

Another key element of the new machine is the crab cavities. Unlike standard radiofrequency cavities, crab cavities produce a rotation of the beam by providing a transverse deflection of the bunches. This is used to increase the luminosity at the collision points and to reduce the beam–beam parasitic effects that limit the collision efficiency of the accelerator. The crab-cavity concept was explored by the KEKB machine, but it will be implemented for the first time at the HL-LHC for a proton collider.

The current operation of the LHC is often disrupted by the machine powering system breaking down. This also happens because of high levels of radiation caused by the high-energy and high-intensity circulating beams. With even higher luminosity, this problem could prevent the accelerator from performing reliably. New magnesium-diboride-based (MgB_2) superconducting cables capable of transporting electrical currents of 20 to 100 kA have already proven their capability for such large current transport, at a convenient 20 K temperature. In this way, it will be possible to move the power converters from the LHC tunnel to a new service gallery, thereby facilitating technical and maintenance operations and reducing the radiation dose to personnel.

All in all, more than 1.2 km of the current ring will need to be replaced with new components. Using cutting-edge technologies, it will be possible for scientists to significantly extend the discovery potential of the LHC (e.g. providing about a 30% higher mass reach for new particles) without replacing the full ring. This is also a challenge for the experiments, which will have to upgrade their inner detectors and other components to face the higher collision rate (*CERN Courier* January/February 2016 p26).

Based on innovative technological solutions, the HL-LHC will also allow physicists to study in depth the properties of the Higgs boson and any possible new particles that the LHC may discover in future runs. In addition, it will play a decisive role in the future of experimental particle physics because it is the ideal test bed for both technology demonstration and for the design of future accelerators beyond the LHC.

The promising results obtained so far have been possible thanks to the collaborative effort of several institutes in Europe and around the world. It is indeed amazing to realise that since its inception, the HL-LHC has brought together more than 250 scientists from 25 countries. This is confirmation that, today, no big scientific endeavour, however bright and smart it might be, can actually be pursued without the contribution of the whole community.

Since 2010, Lucio Rossi has been head of the High-Luminosity Project at CERN. Rossi joined CERN in 2001, and led the Magnet, Superconductor and Cryostat Group for the LHC Project until 2011. In 2007, he received the IEEE Council of Superconductivity Award for sustained contributions to applied superconductivity. He has authored more than 150 publications in international journals and reviews.

Advertising feature

Subnanometre positioning in a vacuum

Queensgate Instruments, an Elektron Technology brand, specialize in creating nanopositioning and sensing solutions for high-tech industries, with variants for precision measurement in vacuum, radiation and cryogenic environments. The company was founded in 1978 as a spin-off from Imperial College, London, and pioneered the use of capacitive metrology for nanopositioning. With deep roots in academia, Queensgate has stayed firmly involved in cutting-edge research and development, and has a range of market-leading products.

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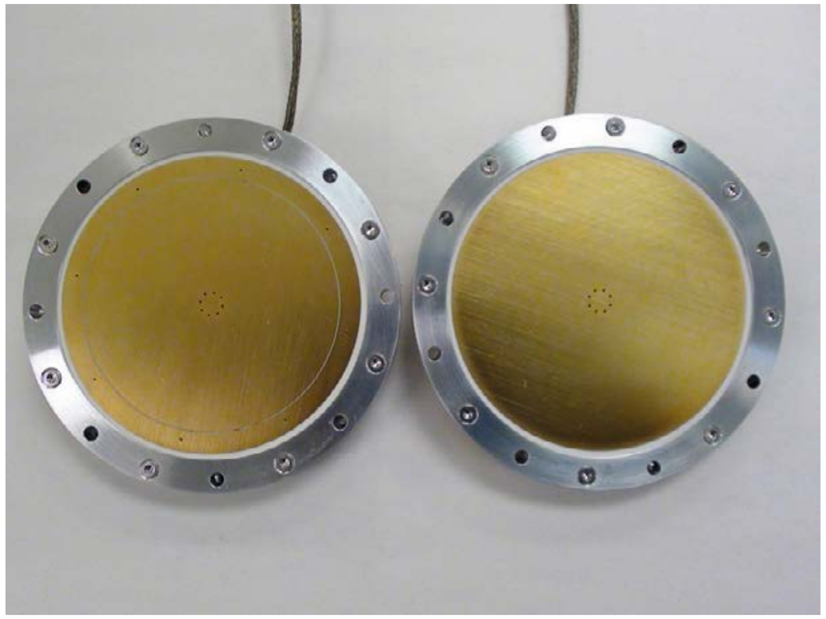
Image: NX capacitive sensor.



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News

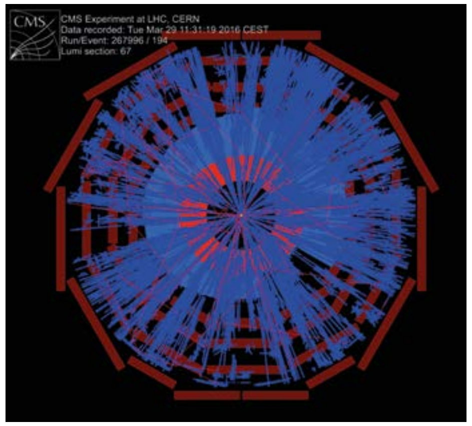
CERN

The LHC: Run 2 has restarted

CERN

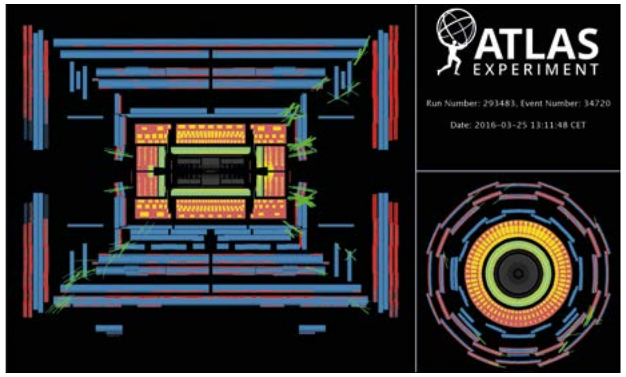
Applause in the LHC control room as the first particles began circulating in the LHC.

CMS



"Beam-splash" events recorded by CMS during the run restart.

ATLAS



ATLAS "beam-splash" events.

At the end of March, the LHC opened its doors to allow particles to travel around the ring for the first time since the year-end technical stop began in December 2015. Progress was good, and the phase of recommissioning with beam could rapidly start. The LHC team worked with low-intensity beam for a few weeks to re-commission all systems and to check all aspects of beam-based operation, to ensure that the LHC was fully safe before declaring "stable beams" – the signal that the experiments could start taking data.

Before the protons could circulate again, the machine underwent the final phase of preparation – known as the machine checkout. During this phase, all of the LHC's systems are put through their paces without beam. A key part of the process is driving the magnetic circuits, radiofrequency accelerating cavities, collimators, transverse dampers, etc, repeatedly through the nominal LHC cycle.

A full programme of beam instrumentation checks took place, to ensure sure that active elements were working and that the complex acquisition chain was functioning properly. Detailed checks were performed on the collimation systems.

The radiofrequency system was re-commissioned and the LHC beam-dump system was subject to stringent operational checks. In parallel, a pilot beam extracted from the Super Proton Synchrotron (SPS) was sent down the two SPS-LHC transfer lines to the beam dumps just before the start of the LHC.

While the machine checkout was ongoing, the experiments were finishing their own last interventions before the closure of the caverns.

2015 saw the start of Run 2 for the LHC, during which the proton–proton collision energy reached 13 TeV. Beam intensity has increased, and by the end of the 2015 run, 2240 proton bunches per beam were being collided. This year, the aim is to increase the number of bunches even further, to the target of 2748. The goal is to reach an integrated luminosity of around 25 inverse femtobarns (fb^{-1}), up from the 4 fb^{-1} reached by the end of last year. One fb^{-1} corresponds to around 80 million million collisions.

Sommaire en français

LHC EXPERIMENTS

At the heart of every LHC collision

At the heart of every LHC collision are the constituents of protons: the quarks and gluons, collectively known as partons. These partons can undergo hard-scattering processes, producing a plethora of final states ranging from the massless to the very massive, such as W and Z bosons or top-quark pairs. Understanding these production cross-sections and their evolution as a function of the centre-of-mass energy, $\sqrt{s}$, of the LHC are important components to understanding all of the measurements performed by ATLAS, including searches for new physics beyond the Standard Model.

Figure 1 illustrates some of the cross-section measurements made by ATLAS at $\sqrt{s} = 7$, 8 and 13 TeV. The new 13 TeV data collected in 2015 greatly extend the lever arm of the investigation of the $\sqrt{s}$ evolution, with increased cross-sections for W and Z bosons and top-quark pairs by factors of approximately two and three, respectively, from their values at 8 TeV.

The final states observed from hard scattering tell a story of which partons participated in the collisions: e.g. top-quark production is related to the gluon composition of the proton, whereas Z-boson production provides insight into the quark sea, and W-boson production on the relationship between the valence quarks. These measurements are pieces of the proton puzzle, and because the $\sqrt{s}$ evolution changes the range of the parton momentum fractions probed by the collisions, the 13 TeV data open up a new kinematic region of investigation.

Via hard scattering, one can also test the predictions of perturbative QCD – a key component of the Standard Model. Single and dibosons are currently predicted at next-to-next-to-leading order (NNLO), and top-quark pair production at NNLO plus next-to-next-to-leading log (NNLL). As $\sqrt{s}$ increases, the mix of the hard-scattering processes changes, and the precision measurements become increasingly dependent on the knowledge of growing electroweak corrections currently available at NLO. With higher $\sqrt{s}$, rarer processes like Z-boson pair production (ZZ) become more accessible and open an enticing window onto potential new physics.

As is evident from figure 1, results match well with Standard Model expectations. Apart from a common beam-luminosity uncertainty, the measurements at 13 TeV have an experimental precision ranging from under 1% for Z bosons, to 3% for W bosons and top-quark pairs, to 14% for ZZ – the latter still being dominated by statistical uncertainties. However, measuring ratios of cross-sections can benefit from the cancellation of many experimental uncertainties. This is evident from the W^+/W^- cross-section ratio at 13 TeV, which has a total systematic uncertainty of less than 1%, rivalling the precision of the current predictions of parton-distribution functions but whose central value is consistently lower than predictions. Results such as those presented here will contribute significantly to the understanding of the large 13 TeV data set expected in the coming years.

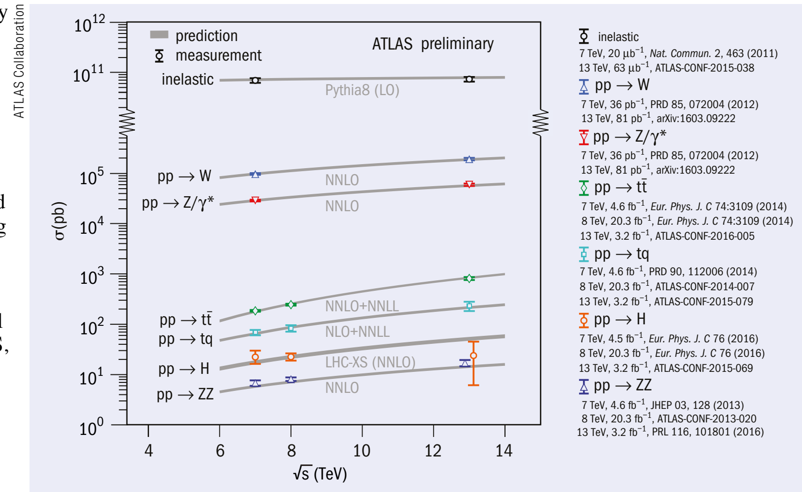


Fig. 1. The figure shows some of the cross-section measurements made by ATLAS at $\sqrt{s} = 7.8$ and 13 TeV, including data collected in 2015.

ALICE finds a new source of charmonium

The ALICE collaboration has studied the production of charmonium – bound states of charm and anti-charm quarks – in hadronic as well as in ultra-peripheral collisions of lead nuclei at $\sqrt{s_{NN}} = 2.76$ TeV. In the latter case, the nuclei do not overlap, and the charmonium is produced through a photonuclear interaction (*CERN Courier* November 2012 p9). Recently, however, ALICE has found a clear signal for what appears to be photoproduction of J/ψ mesons, the lowest vector state of charmonia, also in collisions with significant nuclear overlap.

The nuclear overlap of heavy-ion collisions can be classified based on centrality, which is expressed as a percentile between 0 and 100%, corresponding to head-on and grazing collisions, respectively, or expressed in terms of the impact parameter, which is the distance between the centres of the two colliding nuclei in a plane that is transverse to the beam axis (*CERN Courier* May 2013 p31). The signal is most clearly seen in the transverse-momentum (p_T) distribution shown in figure 1. Hadronically produced J/ψ mesons have a mean p_T around 2 GeV/c, and the spectrum shown in figure 1 is consistent with hadronic production down to a p_T of about 0.3 GeV/c. Below this value, there is a very strong excess, which cannot be reproduced by any model assuming hadronic production, but which is consistent with the sum of the expected hadronic production plus a contribution from coherently photoproduced J/ψ. This last contribution is shown with the Monte Carlo template in the figure. The yield in this region of phase space is about a factor of seven above what is expected from a scaling of the hadronic yield with the number of binary nucleon–nucleon collisions. This unexpectedly large value implies that there is a physics process at play that has not been taken into account in currently available models. Assuming that the underlying process is photoproduction, ALICE obtained the corresponding cross-section.

While in hadronic collisions the nuclei break, they each act as one entity in coherent photoproduction, where the smallness of the p_T is related, via the Heisenberg uncertainty principle, to the size of the lead nucleus. Interestingly, current models of coherent photoproduction integrated over the impact-parameter range corresponding to peripheral collisions predict cross-sections with the right magnitude.

New Pb–Pb collision data at $\sqrt{s_{NN}} = 5.02$ TeV recorded by ALICE in 2015 should allow us to quantify this excess with higher precision and to evaluate its strength in more central collisions. Whether this new source of very-low-p_T J/ψ will provide an additional probe of the properties of the QGP remains an open question.

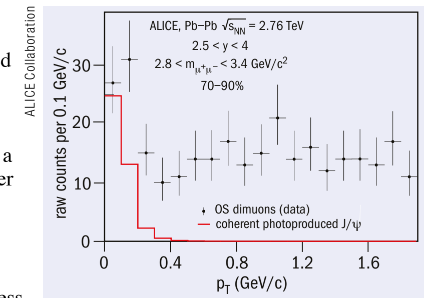


Fig. 1. Lower part of the transverse momentum (p_T) distribution for J/ψ candidates, decaying into two muons with opposite electric charges (denoted OS in the figure), in peripheral collisions of lead nuclei, as measured by ALICE. The red line represents the expectation of coherent photoproduced J/ψ, according to the STARLIGHT Monte Carlo.

Further reading

J Adam *et al.* (ALICE Collaboration) arXiv:1509.08802.

CMS updates its search for diphoton resonances

In December 2015, just a few weeks after the end of the initial LHC Run 2 period recording proton–proton collisions at the world-record collision energy of 13 TeV, CMS and ATLAS presented several new results based on this novel data. These results were eagerly anticipated: at this centre-of-mass energy, new particles heavier than 1–2 TeV could be produced over 10 times more frequently than during Run 1.

The results presented by CMS were based on a data set corresponding to an integrated luminosity of ~2.7 fb^{-1}. Because of the short time between the end of data-taking and the presentation of the results, only preliminary calibrations could be applied. However, these were not all of the data that CMS recorded: an additional 0.6 fb^{-1} were collected without a magnetic field (0 T data set). The cryogenic plant delivering the necessary liquid helium to operate the superconducting solenoid was disrupted during 2015 by the presence of contaminants. The filters inside of the cryogenic plant had to be regenerated several times, in conjunction with the magnet being ramped down. Before continuing the story of the 0 T data set, we want to reassure the reader that the system underwent an extensive programme of cleaning and maintenance during the end-of-year technical stop, and it is now on track for reliable operation in 2016.

The perfect candidate analysis for these data is the search for resonances in the diphoton final state. Preliminary results for this search, shown by CMS and ATLAS in December 2015, generated significant interest within the high-energy community because of a simultaneous excess of data with respect to the expected background seen by both experiments at a diphoton mass of about 750 GeV.

While the momenta of charged particles require a magnetic field to be measured, the energies of neutral and charged particles can be measured with the CMS electromagnetic and hadronic calorimeters without a magnet. Therefore, although challenging, it is still possible to use data collected without a magnetic field through implementation of special and dedicated reconstruction and selection procedures. Photons are neutral particles, which do not bend in the magnetic field, and their energies are measured with a precision better than 1.5% using the CMS lead-tungstate crystal electromagnetic calorimeter. For the 0 T data set, the energy scale and resolution of the electromagnetic calorimeter were carefully cross-checked and adjusted ▷

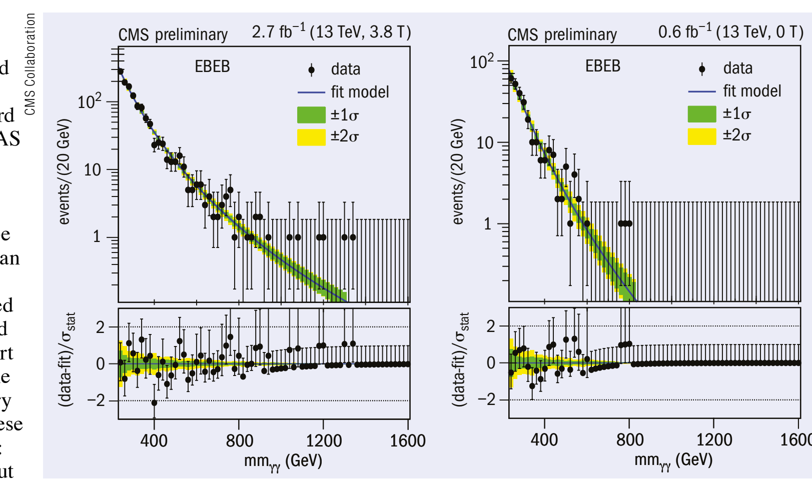


Fig. 1. Invariant-mass distributions for diphoton candidate events, where both photons are reconstructed in the CMS electromagnetic calorimeter barrel (EB). The data are collected at $\sqrt{s} = 13$ TeV, on the left where the magnetic field is at its nominal value of 3.8 T (corresponding to 2.7 fb^{-1} of integrated luminosity) and on the right without a magnetic field (0.6 fb^{-1}).

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using electrons from Z-boson decays. The momentum information normally used for the vertex assignment and isolation criteria was substituted at 0 T by track-counting, as was previously done by CMS in the summer of 2015 for the very first publication on the 13 TeV data, which was a study of the hadron multiplicity without a magnetic field.

The inclusion of the 0 T data and the use of optimised calibrations improve the overall expected sensitivity for a narrow resonance at 750 GeV by about 20%. The new results still exhibit an excess at a mass around 750 GeV. The new local significance for a narrow resonance hypothesis is 2.8σ. When combined with the 8 TeV data set from Run 1, the largest excess is observed at 750 GeV with a local significance of 3.4σ, corrected to 1.6σ when accounting for the possibility of a signal appearing anywhere in the explored mass range. The analysis gives similar results for both spin-0 and spin-2 signal hypotheses.

Therefore, even after the final calibration and with slightly more data, an intriguing excess remains. Only additional data will tell us whether this is an early sign of new physics.

● Further reading
CMS Collaboration 2016 CMS PAS EXO16018.

World's most precise measurements and search for the X(5568) tetraquark candidate

At the Rencontres de Moriond EW conference held at La Thuile (Italy) from 12 to 19 March, the LHCb collaboration presented new important results.

CKM γ-angle measurements. The parameters that describe the difference in behaviour between matter and antimatter, known as CP violation, are constrained in the so-called CKM, or unitarity, triangle. The angles of this triangle are denoted α, β and γ, and among these, γ is the least precisely known. The γ value of $(70.9^{+7.1}_{-8.5})°$ presented at the conference was obtained from a combination of many different LHCb measurements, and is the most precise determination of γ from a single experiment. One of the new analyses presented at the conference uses decays of charged B mesons into charmed D mesons and pions or kaons. In turn, the D mesons decay into various combinations of pions and kaons. The results show different rates of positive and negative B mesons, clearly indicating different properties of matter and antimatter.

Determination of the B^0 oscillation frequency. A fascinating feature of quantum mechanics, in which the B^0_s, B^0 and D^0 particles turn into their antimatter partners, is called oscillation or mixing. LHCb physicists analysed the full Run 1 data sample of semileptonic B^0 decays with charged D or D* mesons, and presented the most precise single measurement of the parameter that sets the B^0-meson oscillation frequency to be $\Delta m_d = (505.0 \pm 2.1 \pm 1.0)\ \text{ns}^{-1}$.

Non-confirmation of the X(5568) tetraquark candidate. Recently, the DZero collaboration at Fermilab reported the observation of a narrow structure, X(5568), in the invariant mass of the B^0_s meson and a charged-pion π (*CERN Courier* April 2016 p13), and interpreted it as a tetraquark candidate composed of four different quarks (b, s, u and d).

At the Moriond conference, the LHCb collaboration reported a result of a similar analysis using a sample of B^0_s mesons 20 times higher than that used by the DZero collaboration. The $B^0_s\pi$ invariant mass spectrum is shown in the figure, using the B^0_s mesons decaying into J/ψ and ϕ mesons or into D_s and π mesons. No structure is seen in the region around the mass of 5568 MeV (indicated by the arrow). Hence, the LHCb analysis does not confirm the DZero result. Using similar kinematic requirements applied by the DZero collaboration in their analysis, the ratio of the X(5568) to the B^0_s-meson production rate is found to be less than 1.6%, at 90% confidence level.

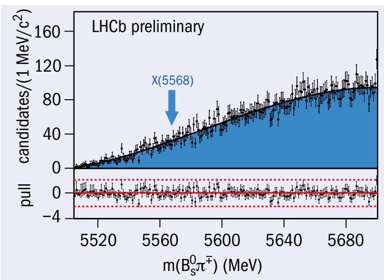


Fig. 1. The figure shows the results from the search for the claimed X(5568) state in a data sample corresponding to 3 fb⁻¹ of pp collision data at √s = 7 and 8 TeV, recorded by LHCb. No significant excess is found in the data set.

● Further reading
https://cds.cern.ch/record/2140095/files/LHCb-CONF-2016-004.pdf.

ASTROPARTICLES

CALET sees events in millions

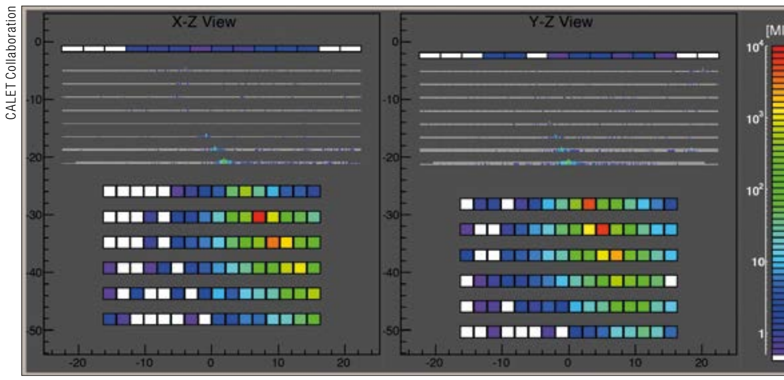
Just a few months after its launch (*CERN Courier* November 2015 p11) and the successful completion of the on-orbit commissioning phase aboard the International Space Station, the CALorimetric Electron Telescope (CALET) has started observations of high-energy charged particles and photons coming from space. To date, more than a hundred million events at energies above 10 GeV have been recorded and are under study.

CALET is a space mission led by JAXA with the participation of the Italian Space Agency (ASI) and NASA. CALET is also a CERN-recognised experiment; the collaboration used CERN's beams to calibrate the instrument, which was launched from the Tanegashima Space Center on 19 August 2015, on board the Japanese H2-B rocket. After berthing with the ISS a few days later, CALET was robotically extracted from the transfer-vehicle HTV5, operated by JAXA, and installed on the external platform JEM-EF of the Japanese module (KIBO). The check-out phase went smoothly, and after data calibration and verification, CALET moved to regular observation mode in mid-October 2015. The data-taking will go on for period of two years, initially, with a target of five years.

CALET is designed to study electrons, nuclei and γ-rays coming from space. In particular, one of its main goals is to perform precision measurements of the detailed shape of the electron spectrum above 1 TeV. High-energy electrons are expected to come from less than a few-thousand light-years from Earth, as they quickly lose energy travelling in space. Their detection might reveal the presence of nearby astronomical source(s) where electrons are accelerated. The high end of the spectrum is particularly interesting because it could provide a clue to possible signatures of dark matter.

The first data sets are confirming that all of the instruments are working extremely well. The event image above (raw data) shows the detailed shape of the development of a shower of secondary particles generated by the impact of a candidate electron with an estimated energy greater than 1 TeV. The high-resolution energy measurement is provided by CALET's deep, homogeneous calorimeter equipped with lead-tungstate (PbWO4) crystals preceded by a high-granularity (1 mm scintillating fibres) pre-shower calorimeter with advanced imaging capabilities. The depth of the instrument ensures good containment of electromagnetic showers in the TeV region.

In the coming months, thanks to its ability to identify cosmic nuclei from hydrogen to beyond iron, CALET will be able to study the high-energy hadronic component of cosmic rays. CALET will focus on the deviation from a pure power law that has been recently observed in the energy spectra of light nuclei. It will extend the present data to energies in the multi-TeV region with accurate measurements of the curvature of the spectrum as a function of energy, and of the abundance ratio of secondary to primary nuclei – an important ingredient to understand cosmic-ray propagation in the Galaxy.



Event image (presented by MIP number) acquired at higher sensitivity, showing an event preliminarily identified as an electron candidate in the TeV region.

***Les physiciens des particules du monde entier sont invités** à apporter leurs contributions aux CERN Courier, en français ou en anglais. Les articles retenus seront publiés dans la langue d'origine. Si vous souhaitez proposer un article, faites part de vos suggestions à la rédaction à l'adresse cern.courier@cern.ch.*

CERN Courier welcomes contributions from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

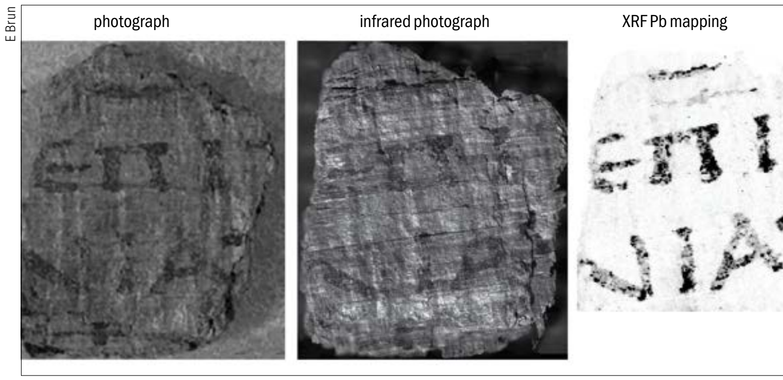
Sciencewatch

Compiled by John Swain, Northeastern University

Metallic Roman ink

Charred Roman scrolls could now be readable, thanks to the fortunate inclusion of lead in Roman inks. Emmanuel Brun of the University of Grenoble and colleagues have found, using synchrotron X-ray fluorescence, and contrary to what had been thought before, that Graeco-Roman ink was used in two Herculaneum papyrus fragments. This non-destructive technique allows imaging and avoids having to unroll the scrolls, which would likely result in their crumbling to dust.

● **Further reading**
E Brun *et al.* 2016 *PNAS* Early Edition pnas.org/cgi/doi/10.1073/pnas.1519958113.



Using synchrotron techniques, a team of scientists has discovered the presence of metal in the ink of two Herculaneum papyrus fragments.

Cold from magnetism

High-current cables can need cooling, but it might be possible to use the magnetic field itself to pull heat away. Luca de' Medici of the European Synchrotron Radiation Facility in Grenoble, France, has pointed out that the Ettingshausen effect could enable this. The idea is to coat the cables with a strong thermomagnetic material like bismuth carrying a small current to pull heat in a direction perpendicular to both the small current and the magnetic field. The effect, while relatively unfamiliar, is analogous to the thermoelectric effect, and can be strong enough to obtain about 60 K cooling for single layers and more than 100 K for double layers. Better thermomagnetic materials could even provide self-cooled superconducting cables that would work at room temperature.

● **Further reading**
L de' Medici 2016 *Phys. Rev. Lett.* **5** 024001.

Bird language

A bird has been found that uses the order in which notes are combined to express meaning. Toshitaka Suzuki of the Graduate University for Advanced Studies in Hayama, Japan, and colleagues played four notes, A, B, C and D, in different orders to the Japanese greater tit (*Parus minor*). ABC makes the bird scan horizontally for predators, repeated D's attract the bird, ABC-D prompted both responses, but D-ABC was apparently uninteresting.

This species normally uses more than 10 different notes, so this is just a start, but it's the first evidence for "compositional syntax" in a wild animal.

● **Further reading**
Nature **531** 278 (17 March 2016) doi:10.1038/531278a.

Efficient wireless power

A new approach to magnetic-resonant wireless-power transfer replaces a wire coil at the transmitter with a high-refractive-index dielectric resonator. Mingzhao Song of ITMO University in St Petersburg and colleagues did numerical work and made a prototype based on exciting the quadrupole mode of a 2 cm-diameter microwave ceramic ball. The dielectric avoids ohmic losses, and the use of the quadrupole mode reduces radiation so that 80% efficiency can be obtained – far higher than the original 45% using metal coils. Rotating the receiver by 90° only reduces the efficiency to 70%. Maybe soon we will be able to throw away our charger cables.

● **Further reading**
M Song *et al.* 2016 *Appl. Phys. Lett.* **108** 023902.

Clever bamboo

Bamboo is an important fast-growing plant (up to 1 m per day has been recorded), providing structural material with high stiffness and low weight. Its stems are hollow, so to avoid collapse on bending, it has "nodes" at which stiff diaphragms separate the stem into cylindrical chambers. The nodes are not evenly spaced, and now Hiroyuki Shima of the University of Yamanashi, Japan, and colleagues have made a detailed study of the physics and revealed "the hitherto unknown blueprint of the optimal node spacing used in the growth of wild bamboo" – a novel expression of biological optimisation.

● **Further reading**
H Shima *et al.* 2016 *Phys. Rev. E* **93** 022406.

Computers suggest experiments

Having trouble thinking of a new and interesting experiment to carry out? How about asking a computer? Mario Krenn of the University of Vienna and colleagues have developed a computer program, MELVIN, which can find new experimental set-ups for how to create and manipulate complicated quantum states. It has already come up with unfamiliar techniques that are not obvious to understand – and which humans might not have come up with using their intuition, which is so rooted in classical physics.

● **Further reading**
M Krenn *et al.* 2016 *Phys. Rev. Lett.* **116** 090405.

Astrowatch

Compiled by Marc Türler, ISDC and Observatory of the University of Geneva, and CHIPP, University of Zurich

Fast radio bursts reveal unexpected properties

Two studies show that fast radio bursts (FRBs) have a richer phenomenology than initially thought and might originate in two different classes. While a group could, for the first time, pinpoint the location of a FRB and constrain baryon density in the intergalactic medium, a second study has found repeated FRBs from the same source, which cannot be of cataclysmic origin.

FRBs are very brief flashes of radio emission lasting just a few milliseconds. Although the first FRB was recorded in 2001, it was detected and recognised as a new class of astronomical events only six years later (*CERN Courier* November 2007 p10). It has been overlooked until re-analysis of the data searching for very short radio pulses. Since then, more than 10 other FRBs have been detected, and they all suggest very powerful events occurring at cosmological distances (*CERN Courier* September 2013 p14). Unlike for gamma-ray bursts (GRBs), there is a way to infer the distance via the time delay of the pulse observed at different radio frequencies. This delay increases towards lower radio frequencies and is proportional to the dispersion measure (DM), which refers to the integrated density of free electrons along the line of sight from the source to Earth.

The real-time detection of a FRB at the Parkes radio telescope has now made it possible, for the first time, to quickly search for afterglow emission, which has routinely been done for GRBs for more than a decade (*CERN Courier* June 2003 p12). Only two hours after the burst, the Australia Telescope Compact Array (ATCA) observed the field and identified two variable compact sources. One of them was rapidly fading and is very likely the counterpart of the FRB. This achievement is reported in *Nature* by a collaboration led by Evan Keane of Swinburne University of Technology in Australia and project scientist of the Square Kilometre Array Organisation.

What makes the study so interesting is that the precise localisation of the afterglow allowed identification of the FRB's host galaxy and, therefore, via its redshift of $z = 0.492 \pm 0.008$, the precise distance to the event. With this information, the DM can be used to measure the density of ionised baryons in the intergalactic medium. The obtained value of $\Omega_{IGM} = 4.9 \pm 1.3$, expressed in per cent of the critical density of the universe, is in good agreement with the cosmological determinations by the WMAP and Planck satellites.

Danielle Futselaar

Artistic rendering of repeating fast radio bursts from a distant source with, in front, the suspended support platform of radio receivers of the 305 m Arecibo telescope in Puerto Rico.

The second paper, also published in *Nature*, reports the discovery of a series of FRBs from the same source. A total of 10 new bursts were recorded in May and June 2015, and correspond in location and DM to a FRB first detected in 2012. This unexpected behaviour was found by Paul Scholz, a PhD student at McGill University in Montreal, Canada, sifting through data from the Arecibo radio telescope in Puerto Rico. The recurrence of bursts on minute-long timescales cannot come from a cataclysmic event, but is likely to be from a young, highly magnetised neutron star, according to lead author Laura Spitler of the Max Planck Institute for Radioastronomy in Bonn, Germany. It is likely that this FRB is of a different nature to other FRBs.

The status of the field is reminiscent of that of GRBs in the 1990s, with the first afterglow detections and redshift determinations in 1997, and the earlier understanding that soft gamma repeaters are distinct from genuine extragalactic GRBs, which are cataclysmic events like supernova explosions and neutron star mergers.

Further reading

E F Keane *et al.* 2016 *Nature* **530** 453.

L G Spitler *et al.* 2016 *Nature* **531** 202.

Picture of the month

This stunning image by the Hubble Space Telescope shows the central region of the Tarantula Nebula in the Large Magellanic Cloud (Picture of the Month, *CERN Courier* June 2012 p12). The young dense star cluster R136 is only a few million years old, and contains hundreds of young blue stars. In addition to this image by the Wide Field Camera 3, astronomers used the ultraviolet-imaging spectrograph STIS – installed by astronauts in 2009 – to identify nine monster stars with masses more than 100 times that of the Sun. One of them is the previously identified record-holder R136a1, which keeps its place as the most massive star known in the universe, at more than 250 solar masses. These hefty stars are destined to explode as supernovas in a few million years.

NASA, ESA, P Crowther (University of Sheffield)

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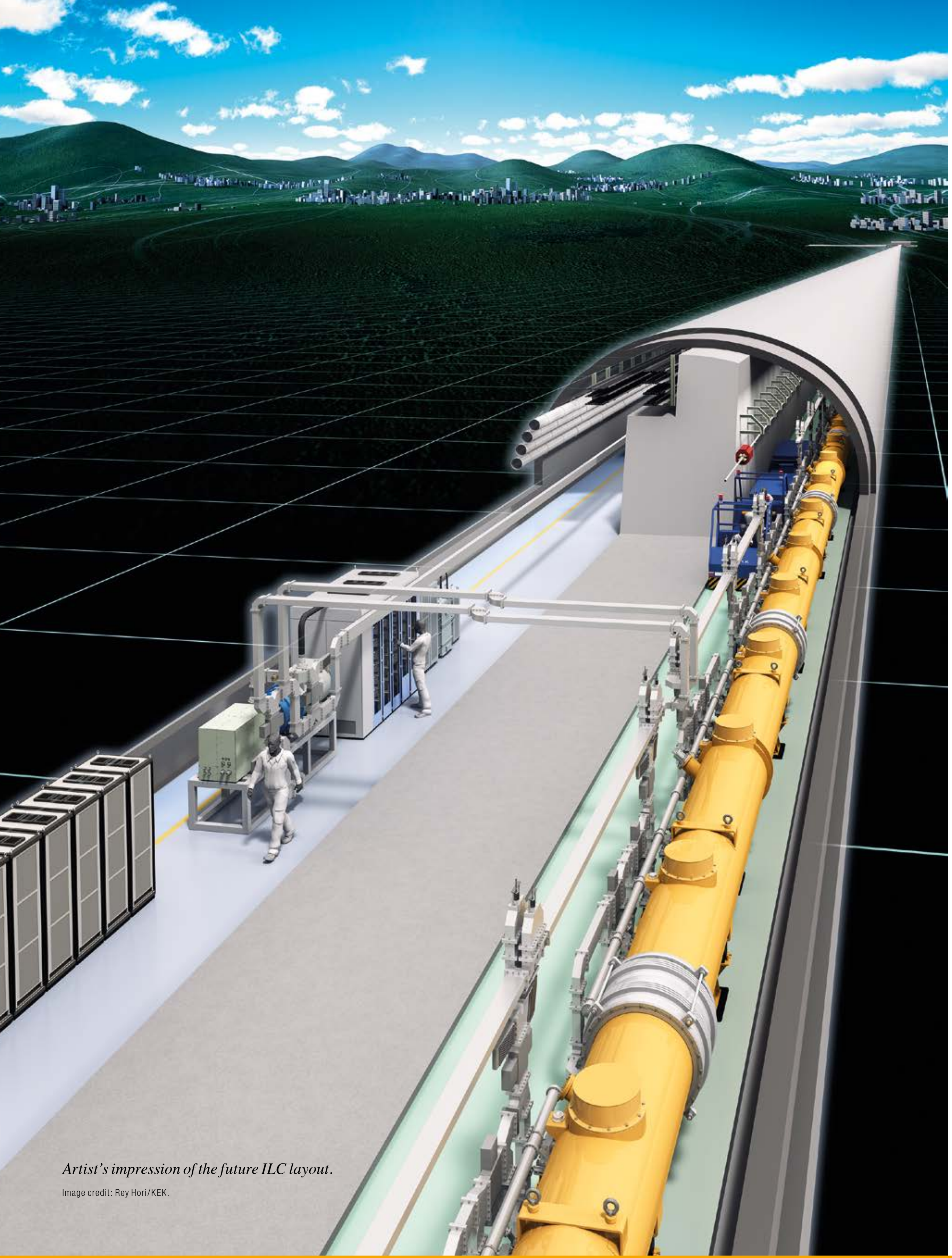


Artist's impression of the future ILC layout.

Image credit: Rey Hori/KEK.

The ILC project keeps its momentum high

Although no decision has been taken so far as to whether or not the proposed new particle accelerator should be built, the R&D programme on key aspects of its design doesn't stop.

Perrine Royole-Degieux, CNRS-IN2P3, **Rika Takahashi**, KEK, and **Barbara Warmbein**, DESY.

It's been three years since the worldwide community of the International Linear Collider (ILC) published its Technical Design Report (TDR). The proposed new particle accelerator would smash electrons and their antiparticles, positrons, into each other at energies of 500 GeV. However, even though the ILC features on all particle-physics road maps worldwide, no decision has been taken so far as to whether or not it should be built. In the meantime, R&D continues on key aspects of the state-of the-art accelerator and detectors, with particular focus on those aspects of the design that depend on where the machine would be built. A proposed site exists, and, if it goes ahead, the machine would be built underneath the lush hills of a region in northern Japan called Kitakami, in Iwate province, some three hours north of Tokyo. The green light depends on commitments from and negotiations between many governments, notably the Japanese, which hasn't yet confirmed its willingness to host the world's next big particle-physics adventure.

The ILC is said to complement results from the LHC because of the different nature of its collisions. Whereas the LHC collides protons with protons, the ILC would collide electrons with their antiparticles, positrons, with the option of starting out as a Higgs factory at 250 GeV and upgrading to 1 TeV in other stages. The physics case has recently been summed up in a paper published in the *European Physical Journal C*: "Due to the collision of point-like particles the physics processes take place at the precisely and well-defined initial energy $\sqrt{s}$, both stable and measurable up to the per-mille level," the paper states. The energy at the ILC is tunable, which allows precise energy scans to be carried out and permits kinematic conditions for the different physics processes to be optimised. In addition, the beams can be polarised: the electron beam up to about 80%, the positron beam up to about 30%. Due to all of these circumstances, it is possible to fully reconstruct the final states so that numerous observables such as mass and total cross-sections, but also differential energy and angular distributions, are available for data analyses. For more information, see *Eur. Phys. J. C* 2015 **75** 371 doi:10.1140/epjc/s10052-015-3511-9.

Precise, efficient and novel systems

The ILC would use superconducting radiofrequency technology to accelerate its particles. Some 16,000 1 m-long accelerating cavities made of pure niobium with an accelerating gradient of up to 35 MV/m are needed to get electrons and positrons up to speed. The final-focus system needs to be extremely precise and efficient if collisions at the design luminosity of $2 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$ are to occur in the two detectors. The detectors – after planning, design and testing by universities from around the world, involving many students – will take turns to sit in the interaction point. A novel system called "push–pull", where one detector is pushed into the interaction point while the other is pulled out so that one can take data while the other is being serviced, was devised in the course of the R&D work for the project's TDR, published in 2013. Compared with the option of switching the beam between two separate interaction regions, this option managed to cut the estimated cost by a significant amount because it eliminated several kilometres of tunnel and some cubic metres of cavern digging in one go.

The TDR sets the estimated cost of the project at $7.8 billion plus 23 million man-hours. This includes all civil engineering, technology production, construction, the accelerator components, etc, but it does not include detectors, contingency, escalation or operation costs. "The basis of the final design and the future construction for the ILC project has been completed, and we're basically ready to push the green button," said then-ILC-director Barry Barish, who led the team of physicists and engineers from around the world who formed the Global Design Effort (GDE) from 2005 to 2013, and who took the project to a construction-ready stage. Three previous regional projects (NLC, JLC and TESLA) needed to be combined into the best and most cost-effective option. People were busy evaluating one option against others, coming up with new ones, checking compatibilities and ▷

The ILC is said to complement results from the LHC because of the different nature of its collisions.

DESY

The ILC will need 16,000 of these superconducting radiofrequency cavities.

keeping an eye on the cost. Despite some major setbacks along the way, the R&D work culminated in the TDR. But even though the maturity of the technologies would allow for the machine to be built tomorrow, tunnel-boring machines have to wait for the official green light.

With the publication of the TDR, the mandate of the GDE ended, and a new organisation was put in place: the Linear Collider collaboration, or LCC. Barry Barish returned to LIGO to find gravitational waves and Lyn Evans took over and united the friendly competitors, the ILC and the Compact Linear Collider (CLIC) study, under one organisational roof. Even though the two linear colliders have very different designs, there are still synergies to be exploited between them. Detector developers, for example, work closely together on such state-of-the-art parts like high-granularity calorimeters as part of the CALICE collaboration. These high-granularity calorimeters have, in fact, spun off to the LHC, and will be used in the CMS detector's calorimeters for the high-luminosity upgrade.

Move from technology to diplomacy

Lyn Evans, former LHC project leader and director of the Linear Collider collaboration, founded in 2013, calls the process a move from technology to diplomacy. Together with his team of project and regional directors, he is busy facilitating negotiations between state officials from various countries to get the approval process under way. The process is slow, and requires many small steps and a large number of study groups and committees; while Japan needs reassurance from governments and funding agencies of potential future member-state countries, to take a decision to host, partner states would prefer to hear "Let's go!" from Japan, before committing themselves to vast amounts of money and manpower. To break an impasse, discussions between political leaders from relevant countries and proactive approaches by scientists to the governments of their countries are under way. A decision is expected sometime around 2018.

Research and design work hasn't stopped, though. The main focus is now on adapting the generic collider design to the specifications of the future site. For example, access shafts and tunnels have been adapted to the geology that exists at the site. With the help of a civil-engineering tool originally developed for the Future Circular Collider study, the interaction region has now shifted by a few kilometres so that detector parts can be lowered into the cavern vertically, rather than needing to be driven in on an inclined slope. Engineers are looking at the nearest port that would receive most of the huge accelerator and detector parts from around the world, and at the bridges that these components would need to cross. One might expect doubts, even fear, from the local community, but the contrary is the case: pro-ILC banners, drawings, bumper stickers and flags along roads are visible proof of the region's support. Local governments have set up ILC promotion offices manned by international residents of Japan, who make sure that everybody in Kitakami not only knows about but also gives their blessing to the ILC. Hitoshi Yamamoto, professor at Tohoku University, tells of the support that he witnessed during a recent site visit of the civil-engineering group: a grandfather and granddaughter saw the group of researchers standing on a field and walked up to them. The group expected to be told to go away, but instead the grandfather pointed at his granddaughter, saying "Please try your best to build the ILC – for this child."

The main focus is now on adapting the generic collider design to the specifications of the future site.

A new international science project would undoubtedly bring benefits to the region, even though the global nature of the ILC would mean that components and parts would be built and tested in labs ▷

ILC

Cherry blossom and science support: the potential host region in northern Japan is very keen to welcome the ILC.

and universities around the world, and then shipped to their final destination, mirroring what was done for the LHC at CERN. Industrialisation is therefore a high-priority topic for the ILC community: getting 16,000 high-tech cavities built, tested and shipped halfway around the world isn't obvious, and researchers are learning a lot from the European X-Ray Free-Electron Laser (European XFEL) currently under construction at DESY in Hamburg, Germany. This uses the same technology as the ILC over a length of some 2 km, providing a neat model for cavity and cryomodule serial production. The European XFEL, which started its life as a spin-off from the TESLA accelerator once planned at DESY, also using SCRF technology, employed two companies for cavity production and devised a complicated (but functioning) ballet of component production, transport, testing and integration between various production places, the companies, DESY, the French CEA laboratory Irfu in Saclay and CNRS lab LAL in Orsay. For the ILC, an order of magnitude more parts will have to be shipped around the world.

Redoubled international efforts

The International Committee for Future Accelerators (ICFA) has decided to continue the linear-collider organisation, and has extended the mandate of the LCC by a year. At the February meeting, ICFA reached a consensus that the international effort, led by ICFA, for an ILC in Japan should continue, and a subgroup has been formed to study the future of the linear-collider organisation and make a proposal for a new structure to be in place from 2017.

ICFA has traditionally been the committee to which the ILC effort reported its progress, the body that set up committees and boards, gave them their mandates and monitored developments. Its partner organisation, the Asian Committee for Future Accelerators (ACFA), met with the Asia-Pacific High Energy Physics Panel (AsiaHEP) in February, and decided to issue a statement about the ILC and the potential circular Higgs factory to be built in China, CEPC. About the ILC, the statement says: "AsiaHEP and ACFA reassert their strong endorsement of the ILC, which is in a mature state of technical development…In continuation of decades of worldwide co-ordination, we encourage redoubled international efforts at this critical time to make the ILC a reality in Japan." About CEPC, it states: "We encourage the effort led by China in this direction, and look forward to the completion of the technical design in a timely manner."

These statements mirror what the strategic road maps for the future of particle physics in the different regions have said: that the physics case for the ILC is "extremely strong" and that the "interest expressed in Japan in hosting the ILC is an exciting development" (P5, US). "There is a strong scientific case for an electron–positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded," states the European Strategy in its fifth recommendation. "Europe looks forward to a proposal from Japan to discuss a possible participation." Obviously all strategies give top priority to the continued operation of the LHC and its future upgrade for operation at higher luminosities, to ensure the exploitation of its full scientific potential, and recommend competitive neutrino programmes and priorities and the development of a post-LHC accelerator project at CERN with global contribution.

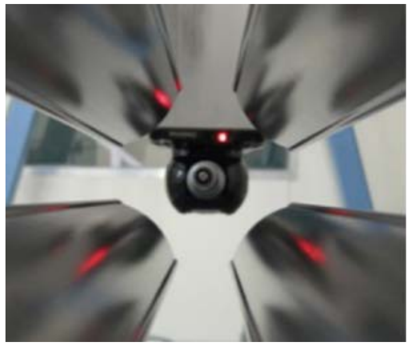
● For further details, visit www.linearcollider.org.

Résumé

Le projet de collisionneur linéaire international a toujours le vent en poupe

Cela fait trois ans que la communauté internationale qui planifie le Collisionneur linéaire international a publié son rapport de conception technique. Le Collisionneur linéaire international est une proposition de nouvel accélérateur de particules, qui ferait entrer en collision des électrons et leurs antiparticules correspondantes, des positons, à une énergie de 500 GeV. Ce projet est inscrit dans toutes les feuilles de route pour la physique des particules, mais il n'a pas encore été décidé, jusqu'à présent, s'il doit être construit ou non. En attendant, la R&D se poursuit sur des éléments essentiels des détecteurs et accélérateurs de pointe, notamment sur les aspects de la conception qui seraient fonction de l'endroit où la machine serait construite.

The Evolution of Multipole Magnet Manufacturing



From left: CNC machined quadrupole pole inspection; EDM wire cut sextupole assembly; EDM wire cutting facilities at Buckley Systems.

Multipole electromagnets perform focusing and higher order corrections in a myriad of particle accelerator applications. Synchrotron light sources are amongst the most demanding of these applications and as the technology has developed, ever tighter multipole magnetic and mechanical specifications have been required. In order to meet this challenge, the way in which multipole magnets are manufactured has also evolved.

Traditionally, synchrotron light source magnets have been laminated from silicon or low carbon sheet steel. Lamination allows for both sorting of steel across magnet families — to produce uniform magnetic properties — and reduced eddy current and hysteresis effects.

Laminations were generally die-stamped, coated with epoxy, stacked, compressed and bonded together as precisely as possible. This technique could cost-effectively produce a large number of magnet yokes with three dimensional pole assembly tolerances in the 40-50 µm range. This was adequate for the magnetic specification of the day. The major disadvantage of the die stamping and bonding method is the high initial cost and maintenance of the die set. It is also difficult to make modifications to the die/lamination profile to correct for stress induced stamping errors or to make changes during the prototyping phase.

An alternative approach, pioneered by Buckley Systems in 2003 for the Australian Synchrotron project, was to laser cut the laminations, bond them together and then CNC machine excess lamination material from the critical pole, mating and fiducial surfaces. This approach produced three dimensional pole assembly tolerances of less than 30 µm. A further advantage of this method is the ability to quickly and inexpensively make changes to either the lamination or pole profile, allowing the designer to take full advantage of the prototyping process.

Recently there has been a drive among 3rd generation light sources for high current, very low emittance electron beams which deliver photons with higher intensity and brightness. This has resulted in tighter multipole magnetic specifications and mechanical tolerances. Buckley Systems' response to this challenge was to enhance the laser cut – bond – machine method by using wire electrical discharge machining (EDM).

In wire cut EDM the laminated steel magnet yoke assembly is submerged in deionised water and a thin wire - supported by upper and lower guides - is passed down the length of the magnet aperture. Current is pulsed through the wire creating an electrical discharge that removes a small amount of steel along the length of the wire. The wire is then slowly and precisely moved along a 2D cutting path. In this manner the pole surfaces can be machined as an assembly, eliminating part tolerance stacking. Fiducial and mounting features can also be wire cut into the assembly, all with tolerances of less than 15 µm.

The wire cut EDM process was used by Buckley Systems to manufacture 90 storage ring multipole magnets for Brookhaven National Laboratory's NSLS II synchrotron light source and all 535 booster and storage ring multipole magnets for Taiwan's NSRRC TPS facility. The wire cut EDM process repeatedly produced high tolerances, enabling the demanding magnetic specifications to be met at production rates of over 30 magnets per month. The figure below shows the normal components of the multipole errors for all 60 quadrupole magnets manufactured by Buckley Systems for the NSLS II project.

Looking forward, there is an increasing demand for higher field, small aperture multipole magnets with low harmonic content. This will require even tighter dimensional tolerances. Buckley Systems has again refined its process and has recently demonstrated sub 10 µm pole profile and pole symmetry tolerances in a prototype quadrupole.

For any further information on electromagnet manufacturing technology and how it could be incorporated into future multipole designs contact Buckley Systems.

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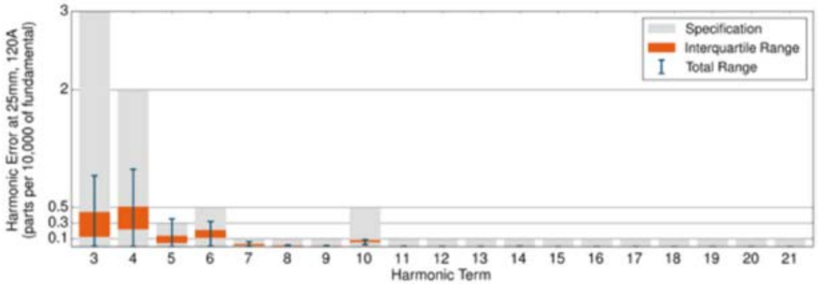


BUCKLEY SYSTEMS

The Tevatron legacy: a luminosity story

The impact of the Tevatron programme extended beyond what was originally planned. To a large extent, this was due to the hundred-fold increase in the delivered luminosity. Based on that experience, many more exciting results from the LHC experiments are yet to come.

Dmitri Denisov, Fermilab, and **Jacobo Konigsberg**, University of Florida.

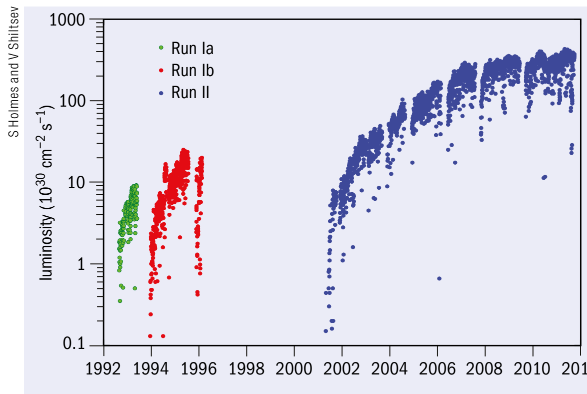


Fig. 1. Tevatron instantaneous luminosity in cm^{-2} s^{-1} between 1992 and 2011.

Throughout history, the greatest instruments have yielded a treasure trove of scientific results and breakthroughs via long-term "exposures" to the landscape they were designed to study. Among many examples, there are telescopes and space probes (such as Hubble), land-based observatories (such as LIGO), and particle accelerators (such as the Tevatron and the LHC).

The long-lived nature of these explorations not only opens up the possibility for discovery of the rarest of phenomena with increases in the amount of the data collected, but also allows a narrower focus on specific regions of interest. In these sustained endeavours, the scientist's ingenuity is unbounded, and through a combination of instrumental and data-analysis innovations, the programmes evolve well beyond their original scope and expected capabilities.

In 2015, the LHC increased its collision energy from 8 to 13 TeV, marking the start of what ought to be a long era of exploration of proton–proton collisions at the LHC's design energy. In December 2015, both the CMS and the ATLAS experiments disclosed intriguing results in their di-photon invariant mass spectra, where an excess of events near 750 GeV suggest the possibility of a new and unexpected particle emerging from the data (*CERN Courier* January/February 2016 p8). With just a few inverse femtobarn of data recorded, the statistical significance of the observation is not sufficient to conclude if this is a coincidental background fluctuation or whether this might be a great new discovery. One thing is certain: more data are needed.

It is worth reflecting on the experience of the Tevatron collider programme, where proton–antiproton collisions at ~2 TeV centre-of-mass energy were accumulated during a 25 year period, from 1986 to 2011. During this time period, the Tevatron's instantaneous luminosity increased from 10^{29} cm^{-2}s^{-1} to above 4×10^{32} cm^{-2}s^{-1} – exceeding by two orders of magnitude the original design luminosity. Figure 1 shows the progression of the initial luminosity for each Tevatron store (in each interaction region) versus time. Also shown in the figure are periods of no data during extended upgrade shutdowns. The luminosity growth was due to the construction of new large facilities, and due to upgrades and better use of the existing equipment. The steady growth of antiproton production was the cornerstone of the growth in luminosity. The construction of the facilities supporting the Tevatron's luminosity growth included the Linac extension in the early 1990s that resulted in doubling its energy to 400 MeV and an increase of the Booster intensity; the construction of the Main Injector (150 GeV rapid-cycling proton accelerator) that greatly increased proton beam power for antiproton production; the construction of the Recycler ring made of permanent magnets and commissioned at the beginning of the 2000s added the third antiproton ring, which was helpful for an increase in the antiproton production rate; and a major upgrade of the stochastic cooling system for the antiproton complex and development and construction of the electron ▷

Programmes evolve well beyond their original scope and expected capabilities.

cooling in the 2000s reduced the antiproton beam emittances. A large number of other accelerator improvements were also key for the Tevatron ultimately delivering more than 10 fb^{-1} of luminosity to each of the two Tevatron general-purpose experiments, CDF and D0. All of them required deep insight into the underlying accelerator physics problems, inventiveness and creativity.

From the measurement of the charged-particle multiplicity in the first few proton–antiproton collisions to the tour-de-force that was the search for the Higgs boson with the full data set of ~10 fb^{-1}, the CDF and D0 experiments harvested a cornucopia of scientific results. In the period from 2005 to 2013, the combined number of publications was constant at roughly 80 per year, with the total number of papers published using Tevatron data reaching 1200, with more coming.

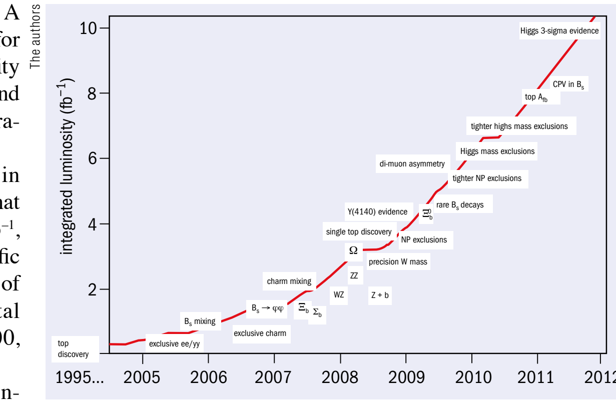


Fig. 2. As the luminosity of the Tevatron increased, with every extra femtobarn, opportunities for new observations and precision measurements opened up.

The results from this bountiful programme include such fundamental results as the top-quark discovery and evidence for the Higgs boson, rare Standard Model processes (such as di-boson and single top-quark production), new composite particles (such as a new family of heavy b-baryons), and very subtle quantum phenomena (such as B_s mixing). The results also include many high-precision measurements (such as the mass of the W boson), the opening of new research areas (such as precision measurement of the top-quark mass and its properties), and searches for new physics in all of its forms. As shown in Figure 2, progress in each of these categories was obtained steadily throughout the whole running period of the Tevatron, as more and more data were accumulated.

The observation of B_s mixing is an example where ~0.1 fb^{-1} of 1990's data were simply not enough to yield a statistically significant measurement. With 10 times more data by 2006, this phenomena was clearly established, with a statistical significance exceeding five standard deviations. As a result, many models of new physics that predicted an oscillation frequency away from its Standard Model expectation were excluded.

With about 2 fb^{-1} of data, enough events were accumulated to firmly establish a new family of heavy baryons containing a b quark, such as Cascade b and Sigma b baryons. Some of these discoveries had ~10–20 signal events, and a large number of proton–antiproton collisions, in addition to the development of new analysis methods, were critical for discovering these new baryons. It took a bit longer to discover the Omega b baryon, which is heavier and has a smaller production cross-section, but with 4 fb^{-1}, 16 events were observed with backgrounds small enough to firmly establish its existence. It was exciting to witness how events accumulated in the corresponding mass peak with each additional inverse femtobarn of data collected.

With more data, many of the systematic uncertainties were reduced.

It was not only discoveries that benefited from more data, high-precision measurements did also. The masses of elementary particles, such as the W boson, are among the most fundamental parameters in particle physics. With 1 fb^{-1} of data, samples containing hundreds of thousands of W bosons became available, resulting in an uncertainty of ~40 MeV or 0.05%. With 4 fb^{-1} of data, the accuracy of the measurement for each individual experiment was of ~20 MeV. With more data, many of the systematic uncertainties were successfully reduced as well. Ultimately, not all systematic uncertainties are better constrained by more data, and those become the limiting factor in the measurement.

Searches for physics beyond the Standard Model are always of the highest priority in the research programme of every energy-frontier collider, and the Tevatron was no exception. The number of publications in this area is the largest among all physics topics studied. Tighter and tighter limits have been set on many exotic theories and models, including supersymmetry. In many cases, limits on the masses of the new sought-after particles reached 1 TeV and above, about half of the Tevatron's centre-of-mass energy.

The observation of the electroweak production of the top quark was among the many important tests of the Standard Model performed at the Tevatron. While the cross-section for electroweak single top-quark production is only a factor of two lower than top-quark pair production at the Tevatron, the final state with such a single decaying heavy particle was very difficult to detect in the presence of large backgrounds, such as W+jets production. It was the search for the single top quark where new multivariate analysis methods were very effectively used for the first time in the discovery of a new process, replacing standard "cut based" analyses and increasing the sensitivity of the search substantially. Even with these new analysis methods, 1 fb^{-1} of data was needed to obtain the first evidence for this process, and more than 2 fb^{-1} to make a firm discovery – almost 50 times more data than the amount of luminosity that was needed to discover the top-quark via pair production in 1995.

The analysis methods developed in the single top-quark observation were, in turn, very useful later on in the search for the Standard Model Higgs boson. The cross-sections for Higgs production are rather low at the Tevatron, so only the most probable decay modes to a pair of b quarks or W bosons contributed significantly to the search sensitivity. With 5 fb^{-1} of data accumulated, each experiment began to be sensitive to detecting Higgs bosons with mass around 165 GeV, where the Higgs decays mainly to a pair of ▷

Physics and data

Fermilab

Fig 3. Vehicle lights create an amazing effect in this night shot of the Tevatron Main Ring.

W bosons. It became evident at that time that the statistical accuracy that each experiment could achieve on its own would not be enough to reach a strong result in their Higgs searches, so the two experiments combined their results to effectively double the luminosity. In this way, by 2011, the Tevatron experiments were able to exclude the Higgs boson in nearly the complete mass range allowed by the Standard Model. In the summer of 2012, using their full data set, the Tevatron's experiments obtained evidence for Higgs boson production and its decay to a pair of b quarks, as the LHC experiments discovered the Higgs boson in its decays to bosons.

Lessons learnt

Among the many lessons learnt from the 25 year-long Tevatron run is that important results will appear steadily as the size of the data set increases. Among the reasons for this are the vast sets of studies that these general-purpose experiments perform. Hundreds of studies, for example, with the top quark or with particles containing a b quark or with processes containing a Higgs boson, provided exciting results at various luminosities when enough data for the next important result in one of the analyses were accumulated. Upgrades to the detectors are critical to handle ever-higher luminosities. Both CDF and D0 had major upgrades to the trackers, calorimeters and muon detectors, as well as trigger and data-acquisition systems. Developments of new analysis methods are also important, enabling the extraction of more information from the data. Improvements in the Tevatron luminosity were critical in keeping the luminosity doubling time to about a year or two, until the end of the programme, providing significant data increases over a relatively short period of time.

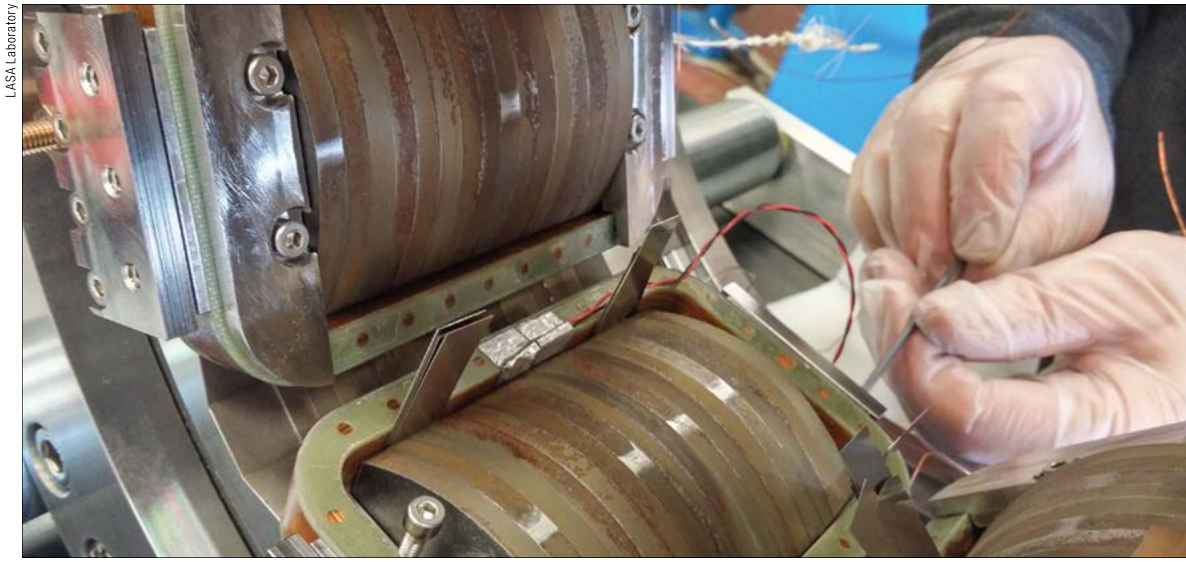
The impact of the Tevatron programme extended well beyond its originally planned physics goals, to a large extent due to the hundred-fold increase in the delivered luminosity with respect to what was originally planned. In many ways, even at a fixed energy, hadron colliders are a nearly inexhaustible source of physics. The LHC has gathered so far approximately 1% of its expected luminosity, a similar situation to where the Tevatron was back in 1995 at the time of the top-quark discovery. Based on the Tevatron experience, many more exciting results from the LHC experiments are yet to come.

● For further details, see www-d0.fnal.gov/d0_publications/d0_pubs_list_bydate.html and www-cdf.fnal.gov/physics/physics.html.

Résumé

Une histoire de luminosité

Les résultats du programme du Tevatron ont largement dépassé les objectifs de physique prévus initialement, en raison notamment de l'augmentation d'un facteur 100 de la luminosité produite par rapport à ce qui était prévu au départ. Même avec une énergie fixe, les collisionneurs d'hadrons sont, à bien des égards, une source presque intarissable de physique. Le LHC a produit jusqu'ici environ 1 % de la luminosité attendue au total, situation similaire à celle du Tevatron en 1995, au moment de la découverte du quark top. Si les choses se passent comme avec le Tevatron, les expériences LHC nous offriront encore beaucoup de résultats exceptionnels !



LASA Laboratory

An expert in the LASA Laboratory (INFN Milan, Italy) works on assembling the first sextupole corrector of the HL-LHC.

Super-magnets at work

The unprecedented requirements of the HL-LHC for magnets are starting to materialise into actual components, which are recording the first positive results.

Luca Bottura and **Lucio Rossi**, CERN.

To obtain 10 times the LHC original design luminosity, the HL-LHC will need to replace more than 40 large superconducting magnets, in addition to about 60 superconducting corrector magnets. A wealth of innovative magnet technologies will be exploited to ensure the final performance of the new machine. Two key features are of paramount importance for the whole project: the production of high magnetic fields and the stability and reliability of the various components.

The backbones of the upgrade are the 24 new focussing quadrupoles (inner triplets) that will be installed at both ends of the ATLAS (Point 1) and CMS (Point 5) interaction regions. These magnets will provide the final beam squeeze to maximise the collision rate in the experiments. They are particularly challenging, because they will have to reach a field of nearly 12 T with an aperture that is more than double that of the current triplets.

In its final configuration, the new machine will have 36 new superferric corrector magnets, of which four will be quadrupoles, and 32 higher-order magnets, up to the dodecapoles. These magnets will also feature a much larger aperture than the ones currently used in the LHC. However, they are designed to be more stable and reliable, to stand the tougher operating conditions of the new machine.

The HL-LHC will also need a more efficient collimation system, because the present one will not be sufficient to handle the new beam intensity, which is twice the LHC nominal design value. For this reason, powerful dipoles will be installed at Point 7 of the ring, in the dispersion-suppression region. The idea is to replace an 8 T, 15 m-long standard LHC dipole with two 11 T, 5.5 m-long new dipoles, therefore achieving the same beam bending strength, but making space to allow the insertion of new collimators in the 4 m central slot. The new dipoles will have a peak field approaching 12 T, comparable to the new inner triplet quadrupoles.

Superferric: strong and reliable

The first HL-LHC magnet, ready and working according to specifications, is a sextupole corrector. This first component is also rather unique because, unlike the superconducting magnets currently used in the LHC, it relies on a "superferric" heart.

Although the name might sound unfamiliar, superferric magnets were initially proposed in the 1980s as a possible solution for high-energy colliders. However, many technical problems had to be overcome, and a good opportunity had to show up, before the ▷

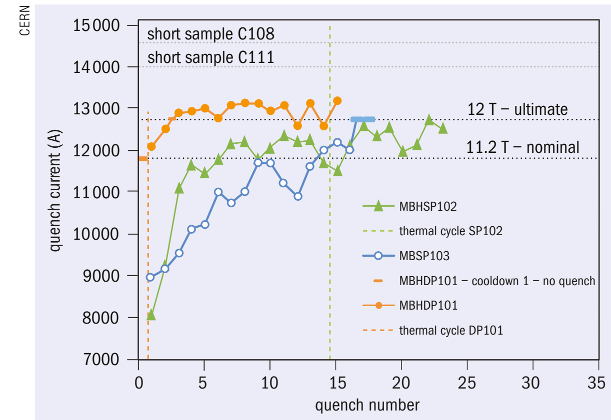


Fig. 1. Training curves of the two 11 T single-aperture dipoles, individually tested (green and blue curves), and of the final assembly as a two-in-one dipole (orange curve).

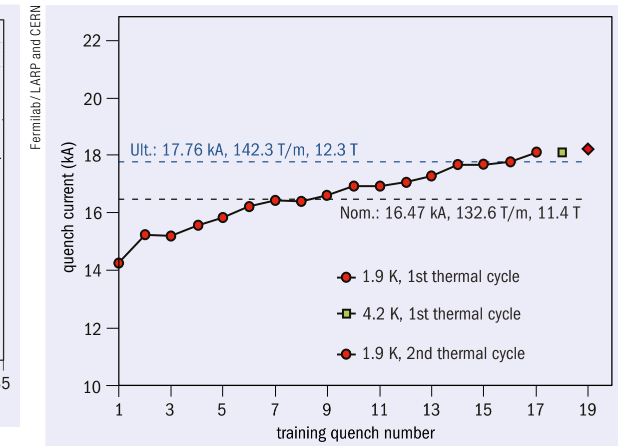


Fig. 2. Training curves of the quadrupoles (triplet) that surpassed a field of 12.3 T.

use of superferric magnets could become a reality.

In a standard superconducting magnet, the iron is used only in the yoke, while in a superferric (or "iron-dominated") magnet, iron is also used in the poles that shape the field, much like classical resistive magnets. In the HL-LHC superferric correctors, the coils are made of Nb-Ti superconductor and will be operated at 1.9 K. The superferric design was selected among other options because it has a sharp fringe field and is very robust. This requirement is crucial for HL-LHC, where it will be essential to sustain the increased radioactive load caused by the collisions of the high-intensity beams.

A superferric corrector magnet had been developed by CIEMAT for the sLHC-PP study (the study that preceded that of the HL-LHC, see project-slhc.web.cern.ch/project-slhc/), and that design was used as a starting point for the HL-LHC correctors. Subsequently, in the framework of a collaboration agreement for the HL-LHC project signed in 2013 between CERN and the Italian National Institute for Nuclear Physics (INFN), the LASA laboratory of the Milan section of the INFN has taken over as a partner in the project.

Recent tests carried out at LASA showed that the sextupole corrector magnet is highly stable, because it could reach and surpass the ultimate current value of 150 A (132 A being the nominal operating value) required by the design specifications before quenching. Actually, the first training quench appeared well above 200 A.

Record dipoles

The HL-LHC is an important test bed for a new concept of dipoles. Built using superconducting niobium-tin (Nb_3Sn) coils kept at a temperature of 1.9 K, the new dipoles will have to reach a bore field of 11 T in stable conditions.

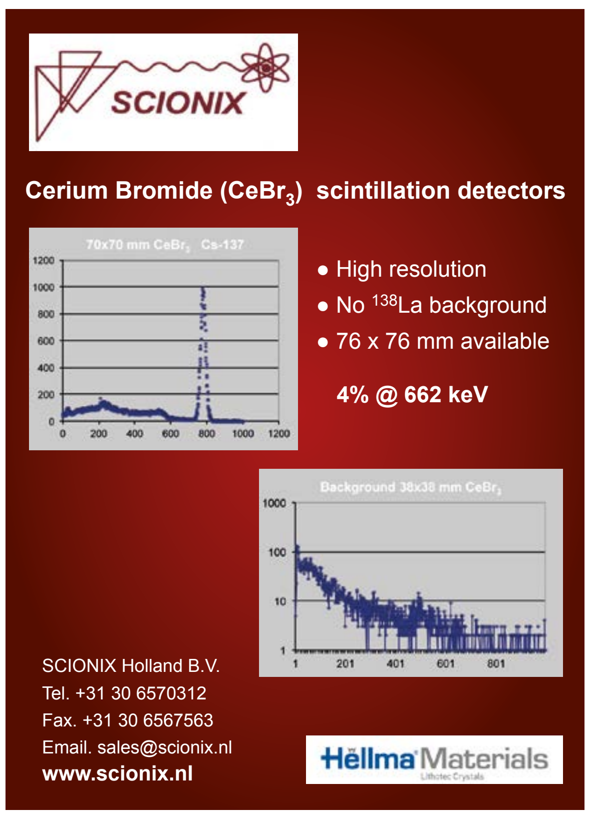
If the expected requirements will be met, the niobium-tin magnets will be crucial to all future collider machines because, for the time being, this is the only technology able to produce magnetic fields greater than 10 T.

Following up on initial successful tests conducted at Fermilab on single-aperture magnets, CERN's experts went on to design and manufacture the first 2 m-long model magnet. While relying on the coil technology developed at Fermilab, the CERN magnet includes some new design features: cable insulation made by braiding S2-glass on mica-glass tape, a new material for the coil wedge, more flexible coil end spacers and a new collaring concept for pre-loading the brittle niobium-tin coils.

Magnets reach their nominal operation after "training" – a procedure that pushes the magnet to the highest possible field before it quenches. Quench after quench, the magnets acquire memory of their previous performance and reach higher fields. In January this year, the first double-aperture (two-in-one) dipole has shown a full memory of the single-coil test, and has established a record field for accelerator dipoles reaching a stable operating field of 12.5 T. Even more relevant to future operation in the LHC, it passed a nominal field of 11 T with no quench, and reached the ultimate field of 12 T with only two quenches (see figure 1).

Even if they will be able to produce a much higher field, the HL-LHC 11 T dipoles are very similar to the standard LHC dipoles, because they must fit in the continuous cryostat and must be powered in series with the rest of the LHC dipoles in a sector. In parallel, the members of the HL-LHC project are developing a bypass cryostat to host the new collimators, which will be inserted between two 11 T dipoles. The new components will allow the machine to cope with the increased number of particles drifting out of the primary beam and hitting the magnets in the cleaning insertions of Point 7. The work is so well advanced that the first collimators should be installed in the dispersion suppression region of the LHC ring during the next long shutdown of the machine scheduled for 2019–2020. They will improve the performance of the LHC during Run 3 and will put the new Nb_3Sn technology to test, in preparation for the final configuration of the HL-LHC.

With an aperture of 150 mm, the focussing quadrupoles currently being developed by the US-LARP collaboration (BNL, FNAL and LBNL) in collaboration with CERN take ▷



Magnet technology

advantage of all of the most advanced magnet technologies. Similar to the 11 T dipoles, they use Nb_3Sn coils and their operating temperature will be 1.9 K. Because of the high field and large aperture, these magnets store an energy per unit length twice as large as that stored in the LHC dipoles. The mechanical structure to contain forces and to assure the field shape is of a new type, first proposed by LBNL, called "keys & bladders". Based on force control rather than dimension control, like in the case of a classical "collars" structure, "keys and bladders" is very well suited for the Nb_3Sn mechanical characteristics (Nb_3Sn is indeed a very brittle material), and it is easy to implement on a limited number of magnets. A special tungsten absorber system, integrated in the beam screen, shields these magnets from the "heavy rain" of collision debris, which will be five times more intense than in the LHC.

At the beginning of March, the LARP teams at Fermilab succeeded in training the first 1.5 m-long model. Designed and manufactured by a CERN–LARP joint team, this is the first accelerator-quality final cross-section model of the inner triplet magnet. Following a very smooth training curve (see figure 2), the model magnet surpassed the operating gradient, which corresponds to a peak field of 11.4 T, actually reaching 12.5 T. Together with the HL-LHC companion 11 T dipole, it is the first built accelerator-quality magnet reaching such fields.

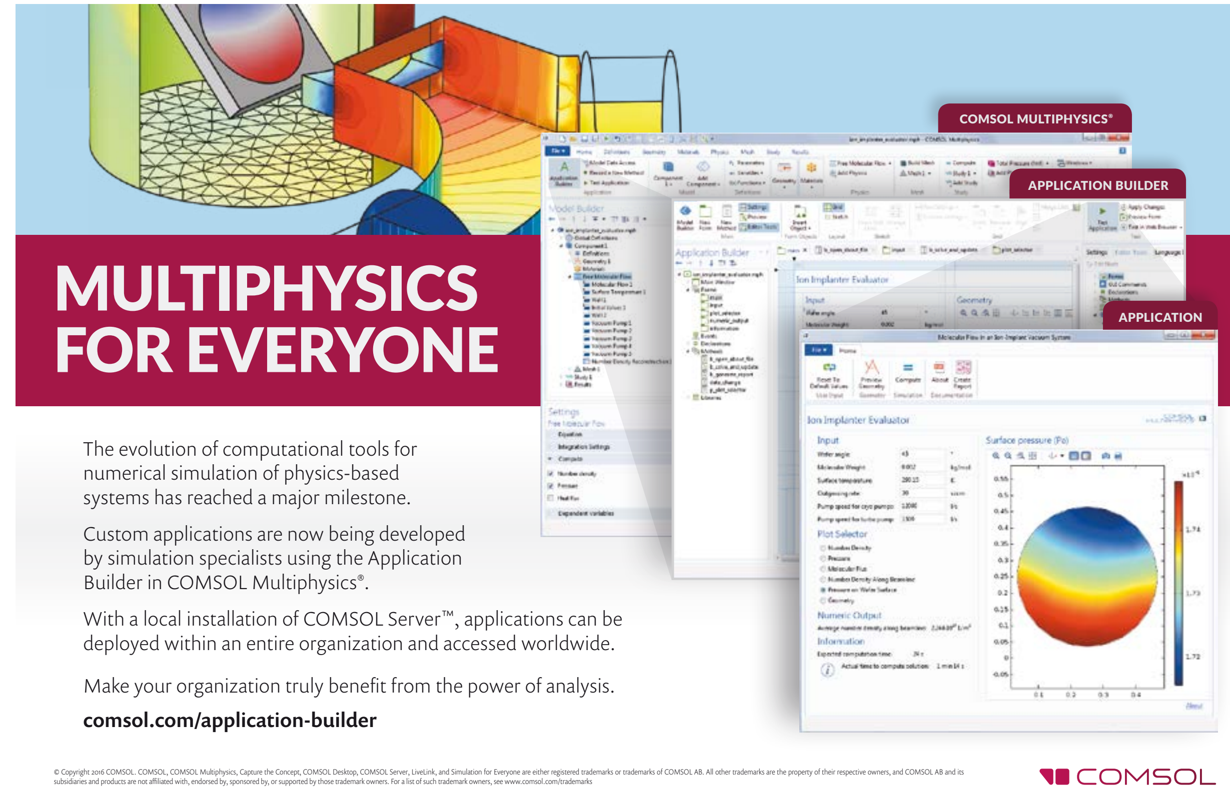
Building on the proven performance of the Nb_3Sn technology, experts from both sides of the Atlantic will go on to build the actual-length quadrupoles. At Fermilab, the final US magnets will measure 4.2 m in length, while the CERN team aims at manufacturing 7.2 m-long quadrupoles to halve the number of magnets to be installed.

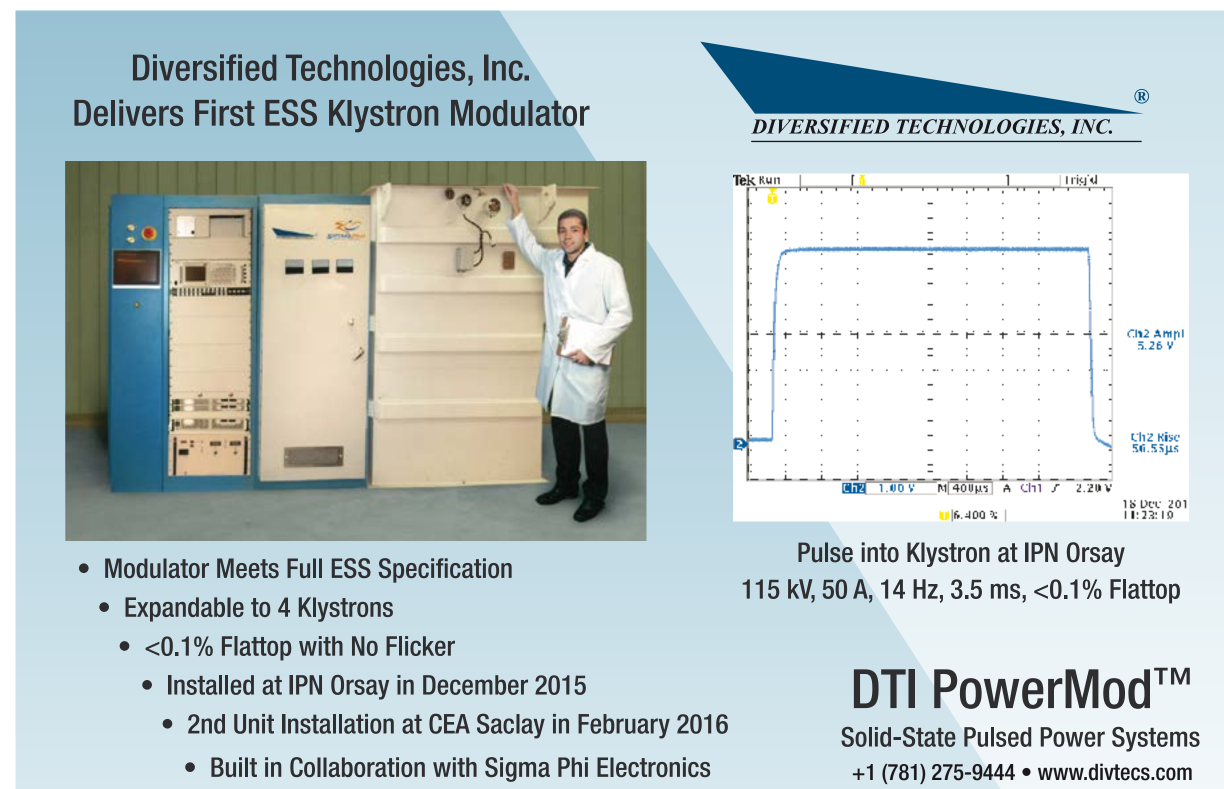
In addition to ensuring the future of collider physics, for which the success of high-field Nb_3Sn for the HL-LHC is a key ingredient, the new powerful magnets will certainly pave the way for their use in other fields, including the medical one. Indeed, the Nb_3Sn technology is already at the core of ultra-high-field magnets used in various fields but not yet in magnetic resonance imaging (MRI), which today represents the largest commercial use of superconductivity. However, the hope is that the development of this technology in the HL-LHC machine may also boost wider use of Nb_3Sn magnets in the medical sector. Indeed, thanks to the higher magnetic fields that can be achieved with Nb_3Sn, MRI systems using this technology would be able to provide more detailed images and faster scanning, e.g. for functional imaging. The challenge is now within reach.

Résumé

Des superaimants à l'œuvre

Afin d'obtenir dix fois la luminosité nominale du LHC, il faudra, pour le HL-LHC, remplacer plus de 40 grands aimants supraconducteurs, ainsi qu'environ 60 aimants correcteurs supraconducteurs. Il sera fait appel à un large éventail de technologies innovantes pour les aimants afin que la nouvelle machine puisse atteindre sa performance finale. La phase d'installation dans le tunnel ne commencera qu'en 2024, mais le premier sextupôle correcteur fonctionne déjà selon les spécifications, et les aimants dipolaires et quadripolaires (triplets) ont quant à eux atteint un champ magnétique dépassant 10 T.





Interactions & Crossroads

Regional events

XXII edition of the EPIPHANY Conference


EPIPHANY Conference

Group photograph of the participants gathered in Cracow to attend the 2016 edition of the EPIPHANY Conference.

More than 100 particle physicists gathered on 7–9 January for the XXII Cracow EPIPHANY Conference on the Physics in LHC Run 2. The international conference, traditionally scheduled early in the particle-physics conference calendar, was held for the first time at the Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN). The organising committee was chaired by the director-general of IFJ PAN, Marek Jeżabek.

The three days of discussions were stimulated by 27 world-class talks on both experimental and theoretical aspects of LHC physics. The four LHC experiments provided a broad spectrum of reports, ranging from impressive accounts of the detector upgrades carried out during the first long shutdown (LS1) and on performance status, through latest physics results, to prospects for Run 2. Energy-frontier physics as well as heavy-ion and heavy-flavour LHC physics were also amply covered. These were complemented by illuminating theory talks, which summarised the current experimental status and outlined possible future scenarios.

It is a long tradition of the EPIPHANY conferences that graduate students and young postdocs are invited to give short talks on their research. This year's edition of the conference featured 25 such presentations by young researchers – a record number. The talks give a unique platform for close interaction between young physicists on the verge of their scientific careers and luminaries in the field – the young researchers not only listen to the enlightening talks of their experienced colleagues and engage in direct discussions, but also have the opportunity to present and promote themselves in front of renowned experts from around the word.

Given its proximity to the new conference venue, attendees were invited on a guided tour of the Cyclotron Centre Bronowice (CCB), an all-new proton-therapy centre recently opened on the IFJ PAN campus.

For the 22nd time, the Cracow EPIPHANY Conference provided an inspiring and friendly environment for discussions within its unique formula, offering lunches and conference dinner to all participants while waiving any conference-fee charges.

● For more information, see epiphany.ifj.edu.pl/current/index.php/page/index.

Winter conferences

Rencontres de Moriond 2016: patience and more data needed

The Rencontres de Moriond in La Thuile, Italy, is traditionally the most important meeting place for particle physicists during the winter. After last year's restart of the LHC at unprecedented energy, and as Rencontres de Moriond celebrates its 50th anniversary, physicists gathered at La Thuile with great interest for the electroweak session (from 12 to 19 March), to look at the latest results from the LHC experiments. Analyses presented during the week included measurements of the Higgs boson using last year's LHC 13 TeV data, an eagerly anticipated update on the search for diphoton resonances, precision measurements of Standard Model processes, and new searches for supersymmetric particles and dark matter.

The week started with many results in the area of heavy flavours, where one of the main highlights came from the LHCb experiment. Looking at their data, LHCb collaboration physicists could not spot any evidence for the existence of X(5568) – a tetraquark particle candidate recently reported by Fermilab's DZero collaboration. The LHCb and DZero collaborations will work together to investigate further, following this interesting outcome.

ATLAS also presented their full Run 1 result of the search for the extremely rare decay of a B_s meson to a muon pair. The decay was observed by CMS and LHCb in 2014, from a combination of their data sets. The ATLAS analysis resulted in a signal that is smaller than expected, but still compatible with the Standard Model.

After a great deal of hard work to calibrate and characterise the data collected, both ATLAS (*CERN Courier* ▷

January/February 2016 p8) and CMS (*CERN Courier* January/February 2016 p9) provided an update on an intriguing result that was first presented last December: a small excess above background in the diphoton channel near a mass of 750 GeV, which could mean the existence of a new unexpected particle, if confirmed. With refined analysis, the "bump" in the data is still there, but the statistical significance of the result still remains too low to be conclusive. Physicists must wait for the imminent restart of data collection before they can investigate further, because the LHC has been paused for the winter during recent weeks.

Physicists will have to wait for summer conferences, such as ICHEP 2016 in Chicago, to possibly get excited again.

● See the News section in this issue for more information.

Events calendar

6–9 June
FPCP 2016
Pasadena, US
The flavour-physics and CP-violation conference was founded in 2002 through the merger of the heavy-flavour (HF) and B-physics and CP-violation (BPCP) conference series. The 2016 edition will be held at the California Institute of Technology.
hep.caltech.edu/FPCP2016/

13–18 June
LHCP 2016
Lund, Sweden
The programme will be devoted to a detailed review of the latest experimental and theoretical results on collider physics, particularly the first results of LHC Run II.
https://indico.cern.ch/event/442390/

4–9 July
NEUTRINO 2016
London, UK
The primary purpose of the conference is to review the status of the field of neutrino physics, the impact of neutrino physics on astronomy and cosmology, and the vision for future development of these fields.
neutrino2016.iopconfs.org/home

3–10 August
ICHEP 2016
Chicago, US
At ICHEP, physicists from around the world gather to share the latest advancements in particle physics, astrophysics/cosmology and accelerator science, and to discuss plans for major future facilities.
www.ichep2016.org

Medical physics

Brainstorming on the needs of the medical field

The second brainstorming meeting on CERN medical applications took place in Divonne, France, from 19 to 21 February. The goal of this series of meetings is to give input to CERN's management on what the medical community would need in terms of imaging for diagnostics, accelerator-based facilities and big data.

Four expert groups on particle therapy, imaging, radioisotopes and nuclear medicine, and medical data, were asked to outline the top priorities, challenges and needs from physics, radiobiology and information sciences in the coming years.

Particle therapy

CERN has the unique capacity to produce a large range of ions from protons to higher z values, at clinically relevant energies, with a control megavoltage photon beam and with long durations of beam-time access.

The clinical priority was stated as studies on relative biological effectiveness (RBE), which would ultimately influence the precise ranges of dose compensation used in clinics when energy-transfer conditions change.

The Bio-LEIR/OpenMed project (https://cds.cern.ch/journal/CERNBulletin/2012/30/News%20Articles/1462262) was also discussed. The members of the expert group see it as an ideal facility to generate new data on RBE on a wide range of cells with different radiosensitivities. Bio-LEIR would also be a test bed for the R&D of compact and sophisticated dosimeters, linear-energy-transfer (LET) detectors, and the remote detection of positron emissions, prompt gamma emissions, and neutrons.

Besides Bio-LEIR, the experts emphasised the strong need for the community to have a common place for sharing experience, ideas, and results. CERN, with its great experience in knowledge exchange and international collaboration, could be the host place for a network, and would be part of a collaboration as member.

Imaging

Medical imaging is a fast-developing field, and predicting the needs for the coming years is an almost impossible task. One of the main points discussed by the experts in Divonne was the new EXPLORER project and the perspectives that it opens. The EXPLORER project, funded by the US, seeks to reduce scanning times, improve sensitivity and spatial resolution, and enable the whole body to be imaged simultaneously with high temporal resolution, by constructing a whole-body PET scanner. It is anticipated that the next generation of EXPLORER will incorporate more advanced detector technology such as that being developed at CERN.

Indeed, electronics and detectors with $\sim$10 ps resolution are under development in various collaborations around the world, including the Crystal Clear collaboration.

Another CERN collaboration, Medipix3, contributed to the development of the "Spectral CT", which offers the possibility of imaging several contrast agents simultaneously. In future, if combined with biomarkers using metal nanoparticles, this technique may even introduce functional imaging to CT.

Accurate dose-range determination during hadron therapy continues to be a key concern. Work continues on various techniques and, in particular, on Compton cameras. Developments in 3-gamma detection may help to improve the efficiency of Compton cameras, leading to improvements in range detection for hadron therapy. A promising approach is the tracking and tagging of charged fragments leaving the patient during ion therapy. Feasibility studies have been carried out at HIT, Germany, using Timepix as the tracking and particle identification detector.

Radioisotopes and nuclear medicine

CERN is constructing MEDICIS (*CERN Courier* November 2013 p37), a dedicated facility for the production of innovative isotopes, which are of potentially high relevance to the medical field. The members of the expert group identified the construction of MEDICIS as a high-priority project that would significantly boost the research on new isotopes. Thanks to MEDICIS, it would be possible to increase the supply of R&D isotopes such as ^{152}Tb and ^{155}Tb. This α emitter is often referred to as the Swiss army knife of nuclear medicine, allowing at the same time imaging by PET and SPECT and treatment of the cancerous cells.

The experts stressed the fact that the best results in this promising field would be achieved through effective collaborations with the European Spallation Source (ESS) currently under construction in Sweden, as well as with the Belgian ISOL@Myrrha. These should also be pursued in view of seeking EU funding from existing schemes.

Medical data

This new topic was introduced this year and immediately became a main focus, first of the ICTR-PHE conference (*CERN Courier* April 2016 p29) and then of the Divonne brainstorming meeting.

Modern medicine increasingly relies for research, diagnoses and treatment on the use of large multifactorial preclinical and clinical data sets of heterogeneous data such as, but not limited to, images, patient history, genomics, metabolomics, proteomics, simulations, standard lab tests, and microbiome and environmental data.

The use and combination of such data sets is an active area of research, which is anticipated to enable breakthroughs in various medical disciplines and open up entirely new interdisciplinary research fields such as personalised medicine – a medical model that stratifies patients based on all available personal data to inform patient-tailored medical decisions. Indeed, looking at a patient on an individual basis allows for a more accurate diagnostic and specific treatment plan.

CERN's contribution to these efforts could be threefold. First, it can provide the necessary computing infrastructure. Second, it can help in the development and tailoring of data-analytics software tools for the management and analysis of large preclinical and clinical data sets, for biophysical simulations and for the development of decision-support systems. And third, the open culture at CERN can be harnessed to accelerate the development of new tools for data analysis, and to promote the development of new research angles and questions.

In addition, CERN attracts numerous talented students and personnel who constitute an invaluable reservoir of skills and interest that could be harnessed for medical-data projects directly, or via hackathons or competitions of the type organised in the machine-learning community.

The two days of the meeting saw focussed and fruitful discussions. The four reports will be compiled into a single document that will be submitted to CERN's management for discussion and evaluation in the coming months.

Faces & Places

Awards

National Technical University of Athens honours Rolf Heuer

In October 2015, the National Technical University of Athens (NTUA) awarded the degree Doctor *honoris causa* to Rolf Heuer, Director-General of CERN from 2009 to 2015.

Evangelos Gazis of NTUA, in his *laudatio*, highlighted Heuer's "outstanding contribution to the field of particle physics for his excellent management of CERN and his involvement during the LHC commissioning, which led to the discovery of the Higgs boson" (Nobel prize 2012). Heuer was also awarded for his strong involvement in science policy-making, his support of the NTUA particle-physics community, and for his efforts and vision to disseminate scientific and technological results to the general public.

NTUA

From left to right, Dimitris Papantonis, NTUA vice-rector, Evangelos Gazis, professor of the Faculty of Applied Mathematical and Physical Sciences, and Rolf Heuer.

Appointments

Joel Butler elected as the new CMS spokesperson

CERN

Joel Butler will start in September as the new CMS spokesperson.

On 10 February, members of the CMS collaboration Board, the "parliament" of the collaboration, held a ballot to appoint their next leader. The Board chose Joel Butler, who brings a wealth of experience – more than 30 years at Fermilab and more than 10 of those with CMS – to this important management role, leading a collaboration of 3000 people from across the globe.

Prior to joining Fermilab, Butler earned a degree in physics from Harvard University, before pursuing a PhD in experimental particle physics from MIT. Since joining the CMS collaboration in 2005, he has contributed to several endeavours, including the US efforts on the Forward Pixel Tracker and the upgrade project. He led the overall US participation in the collaboration from 2007 until the end of 2013.

Soon after his election, Butler declared that high on his priority list is making sure that all collaborators are able to participate in the collaboration's research easily and to the best of their abilities. When he takes over at the helm later this coming September, CMS will have moved its Run 2 data collection into a higher gear: "These will be years of tremendous opportunities and tremendous challenges. I think the opportunities are obvious: by the end of this period, we'll have close to 100 fb^{-1} of data. We should get the first 25 by the end of this year. It will be enormously exciting to see what nature has in store for us," he said.

While Butler has spent much of his career studying flavour physics, he prefers not to narrow his personal expectations of what CMS might discover over the coming years. "I'm a particle physicist, I want to go find out what's there. I don't have too many profound prejudices over what it should be. I think – I hope – we will see new physics soon. But even if we don't find anything quickly, we will still have a long, long way to go. We have to continue to upgrade CMS and to cast a broad net out wide to try to catch what's out there, because we really don't know what the new physics might be or how much data we need to capture it," he affirms.

"I think we've constructed a fantastic detector that's very well suited to the physics that we're trying to explore. That's an extreme compliment to our founding fathers, who designed a great detector." To ensure that CMS can continue this fruitful exploration, Butler points out that the collaboration has crucial technical tasks in the coming months, such as installing a new pixel tracker and new sensors for the hadron calorimeter during the next year-end technical stop.

Butler takes the reins from a distinguished line of previous spokespersons. He has worked closely with many of them in the past, and says he expects to apply what he has learnt from each of them, when he starts his term. "I've been on the Management ▷

Board and the Executive Board as an adviser to all of them since I joined. The experience that our former spokespersons and many other people in CMS have had over the years is invaluable and had to be a guidepost to our future. We have to take advantage of that experience." However, he is aware of the value of change: "Every successful organisation has to continually try to make successive improvements or it will essentially get stagnant. While CMS is enormously successful, there are things we can do better."

Understandably, Butler is excited to take on his new role in a collaboration in which he has worked for a long time: "I think CMS is an absolutely spectacular collection of people that are really passionate and committed to doing physics. They have tremendous technical and analytical skills and are a pleasure to work with," he says. "It's a tremendous honour to be chosen to do this and I'm going to try to do my best for everybody."

Awards

New awards for artists at CERN

Arts@CERN has recently announced the winning artists of COLLIDE Geneva, ACCELERATE Lithuania and ACCELERATE UAE. CERN's programme fosters creative collisions between science and art, and has also recently launched the COLLIDE International Award – a new collaboration between CERN and the Foundation for Art and Creative Technology (FACT) in Liverpool (UK).

In the framework of the new award, a two-month residency programme will grant the winning artist time to explore and reflect on the crossover between artistic and scientific research at the largest particle-physics laboratory in the world. Consequently, the artist will spend a one-month residency at FACT, developing the winning proposal into production.

Cassandre Poirier-Simon receives a three-month residency at CERN, in the framework of the COLLIDE Geneva programme, which is funded by a joint partnership between the Republic and Canton of Geneva and the City of Geneva. The programme now has a category for "digital writing", so the selected artist can now explore the scientific atmosphere in this way.

In March, the ACCELERATE Lithuania and ACCELERATE UAE juries also announced their respective winners: Julijonas Urbonas and Aisha Juma. These two short-residency awards opened last September, in collaboration with the Rupert Arts and Education Centre in Vilnius, Lithuania and ADMAF in Abu Dhabi, UAE.

Aistė Valiūtė and Daumantas Plechavičius

Shogue Fardan

Artists Julijonas Urbonas from Lithuania (left) and Aisha Juma from the United Arab Emirates (right) were the winners of the ACCELERATE country-specific award, for artists to spend a one-month residency at CERN.

Visit

CERN

On 24 March, the president of the Swiss Confederation, Mr **Johann Schneider-Ammann**, paid a short visit to CERN. The president was welcomed by CERN Director-General **Fabiola Gianotti**, and also met with Frédérick Bordry, director for Accelerators and Technology, Martin Steinacher, director for Finance and Human Resources, and Friedemann Eder, head of CERN's Host States Relations Section. During the visit, the president was accompanied by Erik Reumann, spokesperson of the Federal Department of Economic Affairs, Education and Research, Alexandre Fasel, ambassador and permanent representative of Switzerland to the United Nations Office and other international organisations in Geneva, and Patrick Pardo, counsellor at the Permanent Mission of Switzerland to the United Nations Office and other international organisations in Geneva. The exchanges covered, among other topics, CERN's scientific future (High-Luminosity LHC and beyond) and the strong support of Switzerland as a host state. Here, president Johann Schneider-Ammann (left) and CERN's Director-General Fabiola Gianotti (right) are pictured after signing the guestbook, at the conclusion of the visit.

Obituaries

Heinz Filthuth 1925–2016

Heinz Filthuth, an important figure in the bubble-chamber era at CERN, passed away on 21 January.

Joining the Organization in 1955, Filthuth was among the first physicists employed by CERN, studying cosmic rays with a cloud chamber at the Jungfraujoch in the Swiss Alps. He became a member of the team led by Charles Peyrou that built the first hydrogen bubble chambers at CERN. The 30 cm chamber, completed in 1959, and the 2 m chamber, which followed in 1965, were to be the primary instruments for the study of resonances and strange particles for more than a decade. During the same period, Filthuth also worked with the 80 cm hydrogen bubble chamber built at Saclay, which was exposed to a beam of stopping K^- mesons at CERN's Proton Synchrotron. One of the most prominent results from this experiment was the determination of the relative parity of the Σ and Λ hyperons, which favoured the unitary symmetry (flavour SU(3)) proposed by Murray Gell-Mann and Yuval Ne´eman over a competing theory by Werner Heisenberg.

In 1964, Filthuth accepted a professorship at the University of Heidelberg, where he founded the Institute for High Energy Physics to measure and analyse a large sample of stopping K^- interactions recorded in the 80 cm Saclay chamber at CERN, to enhance the study of hyperon decays. In 1967, he organised the Heidelberg International Conference on Elementary Particles, which participants remembered favourably for many years.

Private communication

Heinz Filthuth, left, with Bernard Gregory, then Director-General of CERN, at the 1967 conference in Heidelberg.

Filthuth also represented Germany on the European Committee for Future Accelerators (ECFA) from 1966 – the beginning of ECFA in its current form – to 1970. He strongly promoted the construction of the Big European Bubble Chamber (BEBC) at CERN, a joint CERN–France–Germany project. BEBC started operations in the West Area, recording interactions from the Super Proton Synchrotron neutrino beam in the mid-1970s.

After leaving academia in 1974, Filthuth, being a gifted experimentalist, continued the development of radiation sensors for a broad range of applications in industry, medicine and science. He collaborated for several years with Georges Charpak on optical imaging and radiography at Biospace Mesures, the laboratory that Charpak founded in Paris in 1989, and more recently developed detectors for the study of microbial communities at the Max Planck Institute for Marine Microbiology in Bremen.

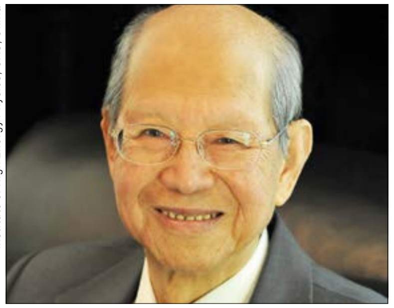
● *His former colleagues.*

Jialin Xie 1920–2016

Jialin Xie, professor at the Institute of High Energy Physics (IHEP), expert in accelerator physics and technology and free-electron lasers, recipient of China's top science award and academician of the Chinese Academy of Sciences (CAS), died on 20 February at the age of 96, in Beijing, China.

Xie was born in Harbin, Heilongjiang province, on 8 August 1920. He graduated from Yenching University, China, in 1943, and in 1947 he moved to the US to continue his studies. At Caltech, Xie obtained his masters degree in physics in 1948, and in 1951 he received his PhD from Stanford University.

Institute of High Energy Physics, CAS, China



Jialin Xie.

From 1951 to 1955, he worked at the microwave and high-energy physics laboratory at Stanford University. He was then in charge of building an accelerator at Michael Reese Hospital in Chicago, which was the highest-energy (45 MeV) medical accelerator in the world, at that time.

In 1955, Xie decided to return to China. Although he was facing many difficulties, including a lack of proper equipment ▷

Faces & Places

and up-to-date information, and even continuous exposure in a dangerous environment, putting his life in danger at times, Xie remained determined to continue with his research.

In 1964, following successful R&D activities on various components of an electron linear accelerator, including an electron gun, a disc-loaded accelerating tube, a high-power pulse modulator, a microwave system and a high-power klystron, he built a 30 MeV electron linac – the first ever built in China. For this important success, Xie was awarded the Scientific and Technological Achievement Prize at the National Science and Technology Conference in 1978.

In 1980, he was elected academician of CAS. During the 1980s, Xie headed the design, manufacture and construction of the Beijing Electron–Positron Collider Project (BEPC), the first high-energy circular collider in China, which produced its first collisions in 1988. In 1990, he was awarded a Supreme Prize for National Science and Technology Progress.

In 1986, Xie proposed the development of the Beijing Free-Electron Laser, a microwave-electron-gun-sourced and linac-based infrared free-electron laser. Using funds provided in 1987 under the State 863 High-Tech Programme, he succeeded in building China's first linac-based infrared free-electron laser, which produced spontaneous emission in May 1993; the lasing reached saturation at the end of 1993. This was the first infrared free-electron laser built in Asia. In 1994, he was awarded the Supreme Prize for Science and Technology Progress by CAS.

Xie published more than 40 scientific papers and several specialised books. As professor of IHEP and guest professor at various universities and institutes, he mentored a great number of accelerator physicists.

In 2015, the International Astronomical Union announced that Minor Planet No. 32928 was to be named after Xie, in recognition of his outstanding contributions in particle-accelerator science. IHEP established a Youth Innovation Fund, which was named the "Xie Jialin Fund".

In April 2016, the Asia Committee for Future Accelerators (ACFA) decided to establish four named prizes, the first being named after Xie. The prize awards lifetime achievements in the field of particle-accelerator science and technology worldwide, with no age limit. The first "Xie Jialin" Prize is to be announced at the IPAC2016 conference, in Korea, this May.

Xie has long been at the forefront of accelerator science-and-technology research, and made a significant contribution to the sustainable development of China's high-energy physics and particle-accelerator science and technology, which had a great impact on the future of the field, both for big facilities and for the younger generation of scientists.

The deepest condolences of all at IHEP and his friends around the world are with his family at this time. May academician Professor Jialin Xie rest in peace.

● *Jie Gao, IHEP, CAS.*

Correction

The birth date in the recent obituary for Namık Kemal Pak (*CERN Courier* April 2016 p34) should have been 1947 and not 1949. The online version has been corrected.

Recruitment

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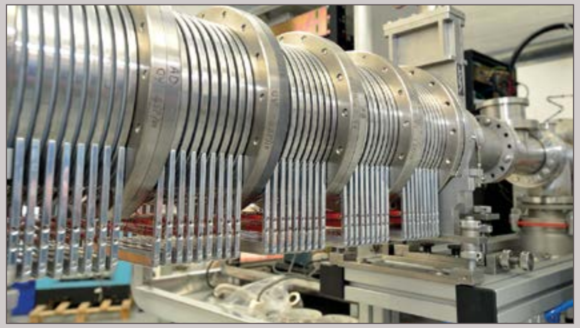

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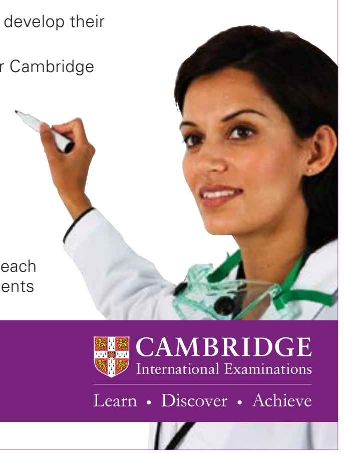

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The Epistemology of the Large Hadron Collider (LHC)

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This research unit investigates a variety of themes centring on the experimental and theoretical research at the Large Hadron Collider (LHC) from an interdisciplinary perspective. It involves problems and methods from philosophy, history, and science studies:

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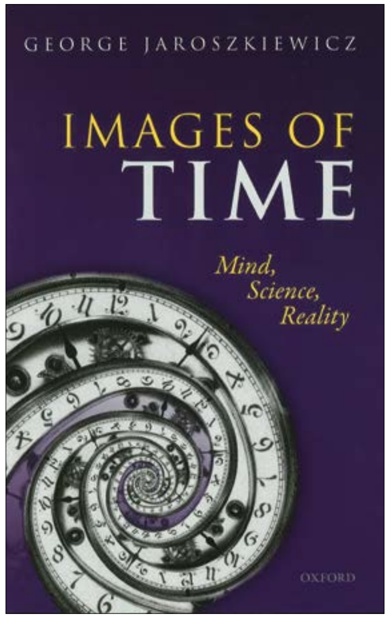
More detailed descriptions of the individual projects, the job requirements, salaries and benefits can be found under http://www.lhc-epistemologie.uni-wuppertal.de.

Applications should be sent electronically to lhc.epistemology@uni-wuppertal.de.
They should include a letter of motivation, a ranked indication of the projects applied for, a cv, a list of publications, copies of diploma, and the name and addresses of referees. For predoctoral positions we expect at least one, for postdoctoral positions at least two references.

Bookshelf

COMPILED BY VIRGINIA GRECO, CERN

Images of Time: Mind, Science, Reality
By George Jaroszkiewicz
Oxford University Press



For ages, sundials have been used to measure time, with typical accuracies in the order of a few minutes. After Galileo discovered that the small oscillations of a pendulum are isochronous, Huygens built the first prototype of a pendulum clock reaching the remarkable accuracy of a few seconds. Today, improved measurements of time and frequency are at the heart of quantum electrodynamics (QED) precision tests. The anomalous magnetic moment of the muon is measured with an accuracy of more than one part in a billion. The global-positioning system (GPS) and satellite communications, as well as other technological applications, are based (directly or indirectly) on accurate measurements of time.

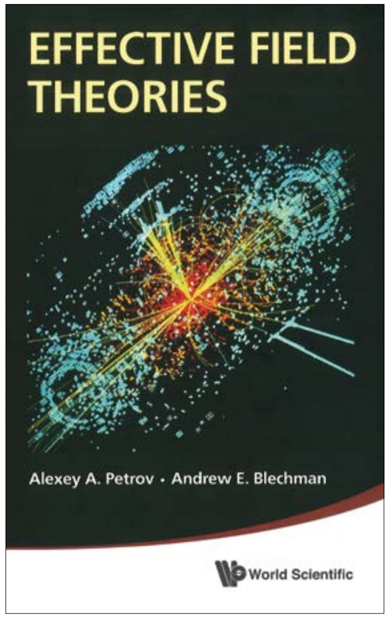
There are some who argue that, while time is measured accurately, its nature is debatable in so far as it appears ubiquitously in physics (from the second law of thermodynamics to the early universe) but often with slightly different meanings. There are even some who claim that time is a mystery whose foundations are sociological, biological and psychological. This recent work by George Jaroszkiewicz suggests that different disciplines (or even different areas of physics) elaborated diverse images of time through the years. The ambitious and erudite purpose of the book is to collect all of the imageries related to the conceptualisation of time, with particular attention to the physical sciences.

The book is neither a treatise on the philosophy of science nor is it a monograph of physics. The author tries to find a balance between physical concepts and philosophical digressions, but this goal is not always achieved: various physical concepts are introduced by insisting on a mathematical apparatus that seems, at once, too detailed for the layman and too sketchy for the scholar. Through the book's 27 chapters (supplemented by assorted mathematical appendices), the reader is led to reflect on the subjective, cultural, literary, objective, and even illusionary, images of time. Each chapter consists of various short subsections, but the guiding logic of the chapter is sometimes lost in the midst of many interesting details. The overall impression is that different branches of physics deal with multiple images of time. Because these conceptualisations are not always consistent, time is perceived by the reader (and partly presented by the author) as an enigmatic theme of speculation. A malicious reader might even infer that after nearly five centuries of Galilean method, the physicists are dealing daily with something they do not quite understand.

This knowledgeable review of the different images of time is certainly valuable, but it fails to explain why improved measurements of time and frequency are correlated with the steady development of modern science in general and of physics in particular. The truth is that physical sciences thrive from a blend of experiments, theories and enigmas: without mysteries driving our curiosity, we would not know why we should accurately measure, for instance, the anomalous magnetic moment of the muon. However, by only contemplating time as an enigma, we would probably still be stuck with sundials.

● *Massimo Giovannini, CERN & INFN Milan-Bicocca.*

Effective Field Theories
By Alexey A Petrov and Andrew E Blechman
World Scientific



The importance of effective field theory (EFT) techniques cannot be over-emphasised. In fact, all theories are, in some sense, effective. A book that discusses these techniques, groups different cases in which EFTs are necessary, and provides numerous examples, is therefore necessary.

After illustrating the ubiquitousness of EFTs with a discussion of Newtonian gravity, superconductivity, and the Euler–Heisemberg theory of photon–photon scattering below the electron mass, the book splits into different directions to examine qualitatively diverse situations where EFTs are used. Fermi theory, chiral perturbation theory, heavy-quark effective theory, non-relativistic quantum electrodynamics (chromodynamics), and even the EFT for physics beyond the Standard Model, are all discussed with a common language that allows the reader to find analogies and appreciate the different physics of these fundamentally different systems.

Soft collinear effective theory (SCET) and non-relativistic general relativity provide a different context in which EFTs are useful as a computational tool. The text exploits the intuition developed in the previous examples to identify the relevant expansion parameters and to organise hierarchically the different contributions to the scattering amplitudes.

Admittedly, the book focuses on high-energy physics topics, neglecting many applications in soft and condensed matter.

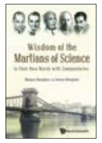
The volume is very well written, it is continuous, and includes a rich introduction on the main topics necessary to understand and use EFTs, such as symmetries, renormalization-group methods and anomalies. As an advanced quantum field theory (QFT) book, it exploits the possibility of relying on the previous knowledge of the reader and concentrates on the relevant issues; the introduction is written in a practical way, providing EFT jargon and highlighting the differences between renormalisable and non-renormalisable theories.

The tone of the book makes it suitable not only for practitioners in the field, but also for students looking for a broad perspective on different QFT topics – the common EFT language providing the thread – and for teachers searching for analogies and similarities between advanced and classical topics.

● *Francesco Riva, CERN.*

Books received

Wisdom of the Martians of Science: In Their Own Words with Commentaries
By Balazs Hargittai and Istvan Hargittai
World Scientific

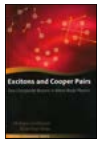


The "Martians" of science that the titles refers to are five Jewish-Hungarian scientists who distinguished themselves for significant discoveries in fundamental science that contributed to shaping the modern world. These great scientists are John von Neumann, a pioneer of the modern computer; Theodore von Kármán, known as the scientist behind the US Air Force; Loe Szilard, initiator of the development of nuclear weapons; Nobel laurate Eugene P Wigner, who was the world's first nuclear engineer; and Edward Teller, colloquially known as "the father of the hydrogen bomb".

Born to upper-middle-class Jewish families and raised in the sophisticated atmosphere of liberal Budapest, they were forced to leave their anti-Semitic homeland to emigrate to Germany, and ultimately to the US, which became their new home country, to the point that they devoted themselves to its defence.

The book comes as a follow-up to a previous title, *The Martians of Science*, which drew the profiles of these five scientists and presented their contributions to their fields of research. The aim of this second volume is to show the wisdom of the Martians by presenting their thoughts and ideas with their own words and putting them into context. Through direct quotes from the five characters and commentaries from other people who knew them, the authors offer an insight into the thinking of such great minds, which they find instructive and entertaining. They are witty, provocative, intriguing and, as the author says, never boring.

Excitons and Cooper Pairs: Two Composite Bosons in Many-Body Physics
By Monique Combescot and Shine-Yuan Shiau
Oxford University Press



This book deals with two major but different fields of condensed-matter physics, semiconductors and superconductors, starting from the consideration that the key particles of these materials, which are excitons and Cooper pairs, are actually composite bosons. The authors are not interested in describing the physics of these materials, but in better understanding how composite bosons made of two fermions interact and, more specifically, identifying the characteristics of their fermionic components that control many-body effects at a microscopic level.

The many-body physics of elementary fermions and bosons has been largely studied using Green functions and with the help of Feynman diagrams for visualisation. But these tools are not easily applicable to many-body physics of composite bosons made of two fermions. Consequently, a new formalism has been developed and a new type of graphic representation, the "Shiva diagrams" (so named because of the multi-arm structure reminiscent of the Hindu god Shiva) adopted.

After two sections dedicated to the mathematical and physical foundation of Wannier and Frenkel excitons and of Cooper pairs, the book continues with a discussion on composite particles made of excitons. In the fourth and last part, the authors look at some aspects of the condensation of composite bosons, which they call "bosonic condensation", and which is different from the Bose–Einstein condensation of free elementary bosons. Other important issues are discussed, such as the application of the Pauli exclusion principle on the fermionic components of bosonic particles.

Although suitable for advanced undergraduate and graduate students in physics without a specific background, this text will also appeal to researchers in condensed-matter physics who are willing to obtain insight into the many-body physics of two composite bosons. ▷

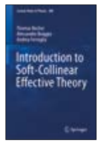
Bookshelf

Introduction to Soft-Collinear Effective Theory

By Thomas Becher, Alessandro Broggio and Andrea Ferroglia

Springer

Also available at the CERN bookshop



The volume provides an essential and pedagogical introduction to soft-collinear effective field theory (SCET), one of the low-energy effective field theories (EFTs) of the Standard Model developed in the last two decades. EFTs are used when the problem that is tackled requires a separation of the low-energy contributions from the high-energy part, to be solved.

SCET has already been applied to a large variety of processes, from B-meson decays to jet production at the LHC. As a consequence, the need was felt for a self-contained text that could make this subject easily accessible to students, as well as to researchers who are not experts in the subject. Nevertheless, a background in quantum field theories and perturbative QCD is a prerequisite for the book.

The basics of the construction of effective theory are presented in detail. The expansion of Feynman diagrams describing the production of energetic particles is described, followed by the construction of an effective Lagrangian, which produces the different terms that contribute to the expanded diagrams. The case of a scalar theory is considered first, then the construction is extended to the more complex case of QCD.

To show the method at work, the authors have included some collider-physics example applications (the field where, in the last few years, SCET has been applied the most). In particular, the soft-gluon resummation for the inclusive Drell–Yan cross-section in proton–proton collisions is discussed, and SCET formalism is used to perform transverse-momentum resummation. In addition, the application of SCET methods to a process with high energetic particles in many directions is analysed, and the structure of infrared singularities in n-point gauge-theory amplitudes derived.

Quark–Gluon Plasma 5

By Xin-Nian Wang (ed.)

World Scientific

As the fifth volume in a series on quark–gluon plasma (QGS), this text provides an update on the recent advances in theoretical and phenomenological studies of QGS. Quark–gluon plasma (also informally called "quark soup") is a state of matter in quantum chromodynamics (QCD) hypothesised to exist at extremely high temperatures and densities, in which the constituents of hadrons, i.e quarks and gluons, are in a special condition of high freedom.

The book is a collection of articles written by major international experts in the field, with the aim to meet the needs of both novices – thanks to its pedagogical and comprehensive approach – and experienced researchers.

A significant amount of space is given – of course – to the impressive progress in experimental and theoretical studies of new forms of matter in high-energy heavy-ion collisions at RHIC, as well as at the LHC. The strong coupled quark–gluon plasma (sQGP) discovered at RHIC has attracted the attention of many researchers and defined the path for future studies in the field. At the same time, the heavy-ion collisions at unprecedented high energies at the LHC have opened up new lines of research.

This updated and detailed overview of QGS joins the previous four volumes in the series, which altogether present a comprehensive and essential review of the subject, both for beginners and experts.

The Composite Nambu–Goldstone Higgs

By Giuliano Panico and Andrea Wulzer

Springer

This book provides a description of a composite Higgs scenario as possible extension of the Standard Model (SM). The SM is, by now, the established theory of electroweak and strong interactions, but it is not the fundamental theory of nature. It is just an effective theory, an approximation of a more fundamental theory, which is able to describe nature under specific conditions.

There are a number of open theoretical issues, such as: the existence of gravity, for which no complete high-energy description is available; the neutrino masses and oscillation; and the hierarchy problem associated with the Higgs boson mass (why does the Higgs boson have so small a mass? Or, in other words, why is it so much lighter than the Planck mass?).

Among the possible solutions to the hierarchy problem, the scenario of a composite Higgs boson is a quite simple idea that offers a plausible description of the experimental data. In this picture, the Higgs must be a (pseudo-) Nambu–Goldstone boson, as explained in the text.

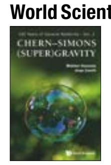
The aim of this volume is to describe the composite Higgs scenario, to assess its likelihood of being a model that is actually realisable in nature – to the best of present-day theoretical and experimental understanding – and identify possible experimental manifestations of this scenario (which would influence future research directions). The tools employed for formulation of the theory and for the study of its implications are also discussed.

Thanks to the pedagogical nature of the text, this book could be useful for graduate students and non-specialist researchers in particle, nuclear and gravitational physics.

Chern–Simons (Super) Gravity – 100 Years of General Relativity (vol. 2)

By Mokhtar Hassaine and Jorge Zanelli

World Scientific



Written on the basis of a set of lecture notes, this book provides a concise introduction to Chern–Simons (super) gravity theories accessible to graduate students and researchers in physics and mathematics.

Chern–Simons (CS) theories are gauge-invariant models that could include gravity in a consistent way. As a consequence, they are very interesting to study because they can open up the way to a common description of the four fundamental interactions of nature.

As is well known, three such interactions are described by the Standard Model as Yang–Mills (YM) theories, which are based on the principle of gauge invariance (requiring a correlation between particles at different locations in space–time). The particular form of these YM interactions makes them consistent with quantum mechanics.

On the other hand, gravitation – the fourth fundamental force – is described by general relativity (GR), which is also based on a gauge principle, but cannot be quantised following the same steps that work in the YM case.

Gauge principles suggest that a viable path is the introduction of a peculiar, yet generic, modification of GR, consisting in the addition of a CS term to the action.

Besides being mathematically elegant, CS theories have a set of properties that make them intriguing and promising: they are gauge-invariant, scale-invariant and background-independent; they have no dimensionful coupling constants; and all constants in the Lagrangian equation are fixed rational coefficients that cannot be adjusted without destroying the gauge invariance.

CERN Courier Archive: 1973

A look back to CERN Courier vol. 13, May 1973, compiled by Peggie Rimmer

CERN NEWS

European Molecular Biology Laboratory

An agreement was signed at CERN on 10 May setting up a new European laboratory for research in molecular biology. Located at Heidelberg in the Federal Republic of Germany, it will be a centre where top-class instrumentation for this type of research can be developed, but more importantly where top-class scientists from the various disciplines involved can work together.

CERN, the venue for many of the debates concerning the laboratory, has been used as a model for how a European research centre should work. The Member States exercise overall control via a council of delegates, as at CERN, while the running of the laboratory is assigned to a Director-General. The Director-General designate is J C Kendrew, project leader in the studies leading to the establishment of the laboratory. Professor Kendrew received the Nobel prize in 1962 [with M F Perutz] for research on protein structure.

Ten countries have signed the Agreement – Austria, Denmark, the Federal Republic of Germany, France, Israel, Italy, the Netherlands, Sweden, Switzerland and the UK. Greece, Norway and Spain have participated in the discussions but are unable to join at present.

● Compiled from text on p139.

CERN 71.5.73

Above right: Dr K Korz, Erste Burgermeister of Heidelberg, speaking at CERN when the agreement establishing a European molecular biology laboratory was signed. On his right (from left to right) are W Jentschke (Director-General of CERN Lab I), H Voirier (president of the European Molecular Biology Conference), R Keller (director of the International Organization Board of the Swiss Federal Policy Department), J C Kendrew (Director-General designate of the new laboratory), R K Appleyard (executive secretary of EMBO) and M Delauche (secretary of EMBC).

BERKELEY

New tunnelling effect with electrons

During the design of the injector for electron-ring-accelerator research at the Lawrence Radiation Laboratory (LRL), it was realised that intense electron beams could cause considerable mechanical damage to materials in their path. While this was studiously avoided, the effect was investigated with a view to applications.

For many reasons, tunnels, underground storage areas, etc, are sometimes preferable to surface constructions. However, associated costs are often prohibitively high, and it was thought worthwhile looking into using electron beams as a cheaper or more appropriate way of cutting through rock.

The phenomenon known as "shock spalling" occurs when intense stresses are created in the rock by locally depositing energy in pulses lasting less than a microsecond. Comparatively modest amounts of energy can initiate stress waves exceeding the tensile strength of the rock, resulting in "mini-explosions" that break off flakes of rock. The waves can travel through the rock and cause further shock spalling at an interior surface.

● Compiled from text on pp149–150.

Photo LBL

Pieces of granite exploding away from a 1 cm slab (the vertical bar) bombarded with a single, intense, 50 ns burst of electrons. The created pressure not only disintegrated the right side of the slab where the electrons entered, but travelled through and fractured the left side too.

LOS ALAMOS

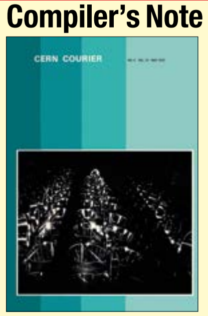
Both positive and negative

At the beginning of April, the 800 MeV Los Alamos Meson Physics Facility (LAMPF) simultaneously accelerated both positive and negative particles. This is possible in linear accelerators because the accelerating fields along the machine swing from one direction to the opposite direction at very high frequency. For tiny fractions of time, particular sections of the machine establish the conditions for accelerating positives, followed by tiny fractions of time with the conditions for accelerating negatives.

LAMPF is therefore provided with two ion sources – one of protons and one of negative hydrogen ions.

● Compiled from text on p154.

Compiler's Note



Cavemen and other early diggers used thermal spalling to help excavate their caverns and tunnels by lighting fires against rock faces and dousing the hot rock with water. Latter-day underground engineers use explosives (not particle beams), and concomitant spalling from roofs and walls due to discontinuities in the rock is more often seen as a problem rather than part of the process.

At the sub-atomic level, shock spallation is employed to create intense bursts of neutrons by shattering heavy nuclei with pulsed high-energy particle beams. LAMPF morphed into LANSCE, the Los Alamos Neutron Science Centre, with the negative hydrogen-ion beam driving a spallation neutron source (SNS) while the positive beam is used primarily for isotope production. The world's most powerful SNS, located at Oak Ridge National Laboratory, was jointly developed by six US labs, including the LRL and LANSCE, and serves an international community of researchers in physics, chemistry, materials science and biology.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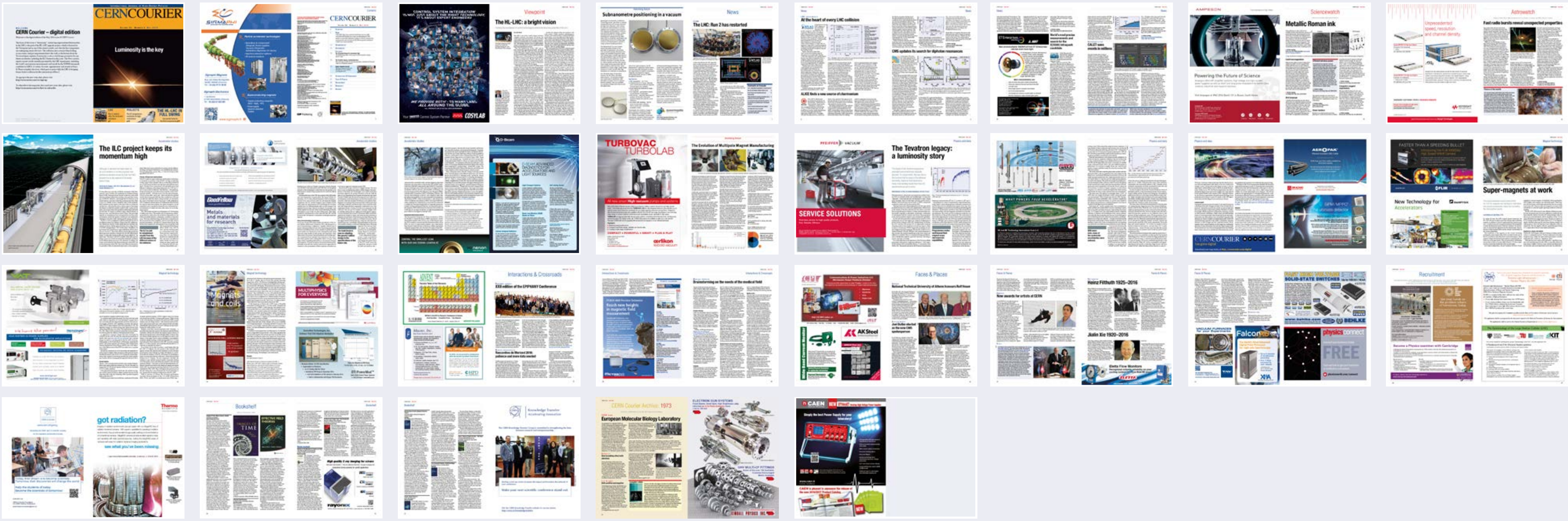

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