WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the July/August 2017 issue of *CERN Courier*.

Initially developed to explore the smallest constituents of matter, particle accelerators have evolved into powerful instruments for numerous other fields and applications. Their biggest impact outside particle physics, alongside their daily use worldwide in hospital diagnostics and treatments, has been the rise of X-ray light-source facilities – the most recent on the scene, the SESAME facility in Jordan, is based on magnet technology developed in collaboration with CERN and the European Commission. Later this year, the most powerful light source ever – the European XFEL in Germany – will begin user operations. It will generate extremely short pulses of coherent X-rays enabling researchers to "film" fundamental processes at the nanoscale, and driving it is the world's longest superconducting linac, based on technology simultaneously developed for a linear collider for particle physics. Also this summer, construction for a major accelerator facility called FAIR began in Darmstadt, to provide beams for the heavy-ion and many other communities by 2025. We also report on a novel accelerator-based application of positron emission tomography developed by particle physicists to improve the efficiency of diamond mines. Of course, subatomic exploration remains the main driver of advanced accelerator projects, as exemplified by the LHC. Five years ago, on 4 July 2012, the LHC enabled physicists to announce the discovery of the Higgs boson, and steady progress is being made towards defining its successor.

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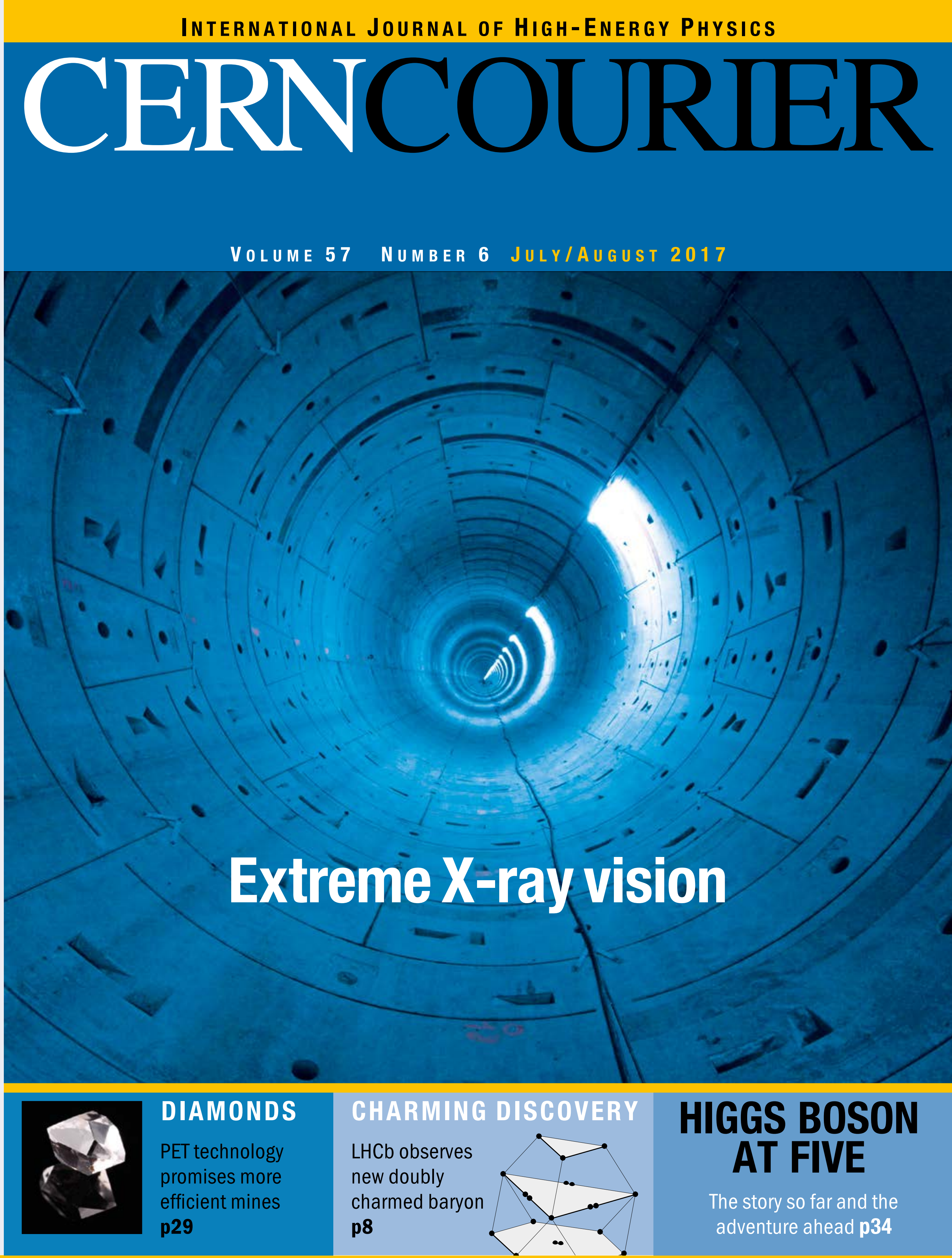

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Covering current developments in high-energy physics and related fields worldwide

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On the cover: View into the 2 km-long main tunnel of the European XFEL in September 2011. (Image credit: European XFEL.)

Viewpoint

Data privacy concerns us all

CERN responds to new European data-protection regulations due to enter force next year.

D Foster

National institutions, companies, laboratories and universities in Europe will soon be subject to the General Data Protection Regulation.

By David Foster

It is perhaps no coincidence that many dystopian visions of the future in popular fiction, such as *Nineteen Eighty-Four*, *Brave New World* and *Fahrenheit 451*, have breach of data privacy at the core of their plots. With an ever growing level of interaction between humans and a global infrastructure tied together by the internet, there is always the fear that others know more about you than you would like. How can we save ourselves from such a bleak future?

The answer has been to create, over the past 20 years, a number of strict legal obligations and rights when dealing with the personal data of individuals. You will notice that you are increasingly asked for consent for use of your personal data on websites and to allow software to store cookies on your computer. Such legislation is sometimes criticised for generating bureaucracy that gets in the way of "real work". But for those who work in the data-privacy arena, it is clear that we need to adapt quickly to a rapidly evolving digital environment. What you do, where you go and how long you spend there are valuable assets in the information world.

In 2012 the European Union (EU) proposed new data-protection reforms to strengthen the fundamental rights of citizens. Three years later, EU institutions reached agreement on the rules, and in May 2016 a new regulation was issued called the General Data Protection Regulation (GDPR), which enters into force in all European Economic Area (EEA) countries from 25 May 2018.

You probably haven't heard much about the GDPR until now, yet it is almost certain to impact the way our field deals with personal data. The central idea is that your personal data is truly yours: it cannot be taken or processed without safeguards to its privacy, and any data collection or processing must have an appropriate legal basis. The new laws offer a very broad interpretation of what "personal data" and "processing" mean, and offer a number of legal bases that must be considered. Personal data is anything that could be used to identify you, including obvious things like name and address but also more subtle information like GPS location or IP address. Processing is equally loosely defined, from storing data in a database to viewing data on a screen and even copying a file.

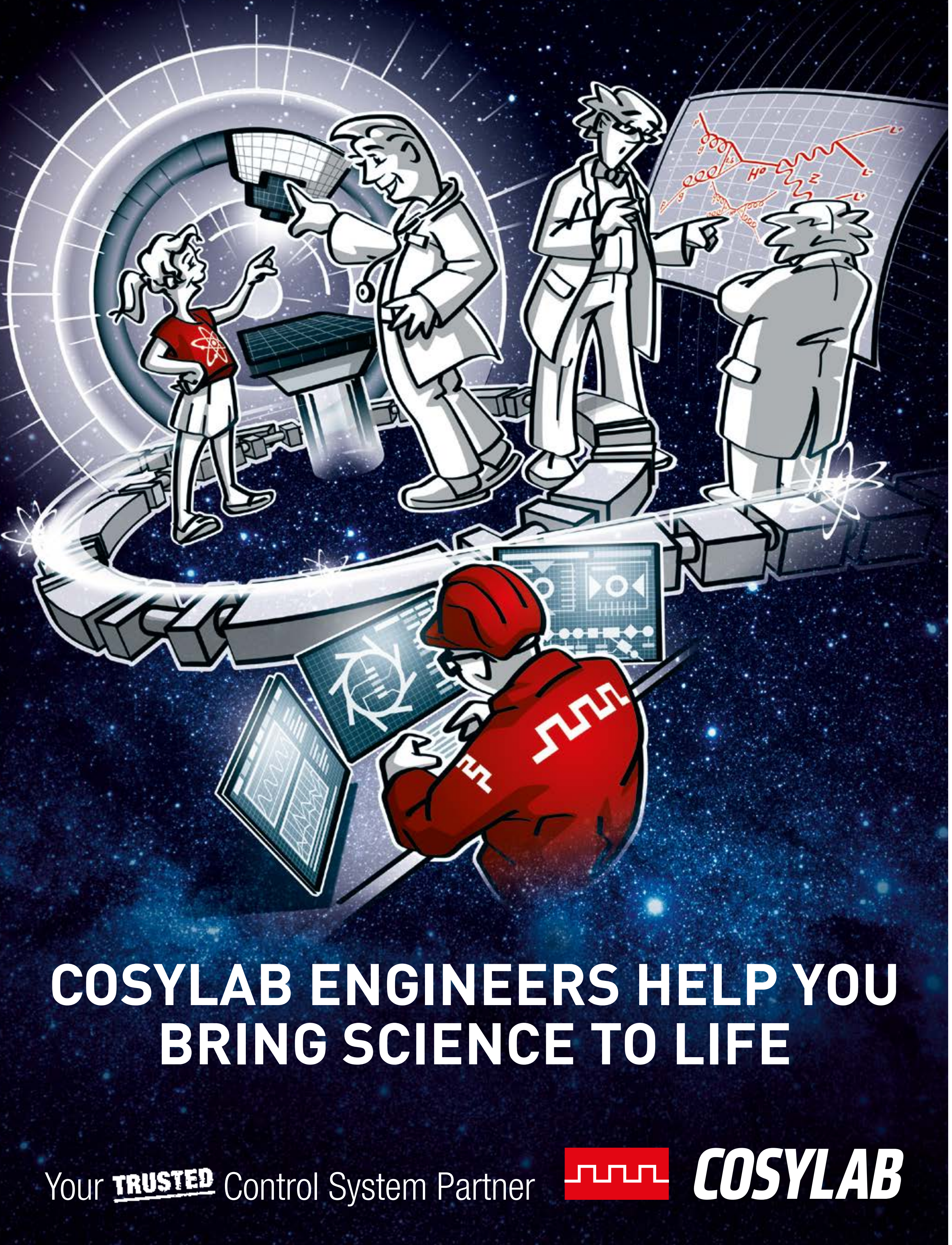
Although in practice there are many details to be determined, the intention of the regulators is evident: to stop the use of people's personal data except for well-defined purposes that must be clear when the data are collected to be fair to the individual. Crucially, the new regulations aim to be technology agnostic and therefore apply equally to online databases as well as a filing cabinet full of paper.

All EEA institutions, companies, labs and universities will be subject to the GDPR. Although CERN, as an international organisation, is not directly subject to EU regulations, in light of the coming changes it is reviewing its internal legislation to offer equivalent levels of personal-data protection. Consequently, in January this year CERN established the Office of Data Privacy Protection to assist services that process personal data and to help anyone who is concerned about how their personal data is being handled by the Organization.

Given the broad scope of personal data and data processing, it can be complicated and somewhat burdensome to comply with these new practices. For instance, it will require us to review how passport information should be sent, how records such as medical information and personal attributes are secured, as well as how photos and CCTV are used. At the same time, we need to recognise that protecting privacy is important and that adopting a "nothing to hide, nothing to fear" approach does not protect us from future unknown uses of our personal data.

So, if in any doubt, simply adopt the golden rule of personal data: if you don't really need it, don't collect and store it; if you do, delete it as soon as possible.

David Foster, formerly deputy head of CERN's IT department, is head of data privacy protection, where he works at the intersection of business, technology and law.



News

INTERNATIONAL

Lithuania joins CERN as associate member

On 27 June, representatives of CERN and the Republic of Lithuania signed an agreement in the capital city of Vilnius admitting Lithuania as an associate Member State. The agreement will enter into force once official approval is received from the Lithuanian government.

"The involvement of Lithuanian scientists at CERN has been growing steadily over the past decade, and associate membership can now serve as a catalyst to further strengthen particle physics and fundamental research in the country," said CERN's Director-General, Fabiola Gianotti. "We warmly welcome Lithuania to the CERN family, and look forward to enhancing our partnership in science, technology development and education and training."

Lithuania's relationship with CERN dates back to a co-operation agreement signed in 2004, which paved the way to participation of Lithuanian universities and scientific institutions in high-energy physics experiments at CERN. Lithuania has been a long-time contributor to the CMS experiment and has also played an important role in developing databases for the experiment. The country actively promoted the BalticGrid in 2005, and more generally participates in detector development relevant to the High Luminosity LHC.

Lithuania's associate membership will strengthen the long-term partnership between CERN and the Lithuanian scientific community. It will allow Lithuania to take part in meetings of CERN Council and its committees, and Lithuanian scientists will be eligible for staff appointments. Finally, once the agreement enters into force, Lithuanian industry will be entitled to bid for CERN contracts.

R Dačkus

CERN Director-General, Fabiola Gianotti, president of Lithuania, Dalia Grybauskaitė, and Lithuanian minister of foreign affairs, Linas Antanas Linkevičius, at the signing of the agreement in Vilnius.

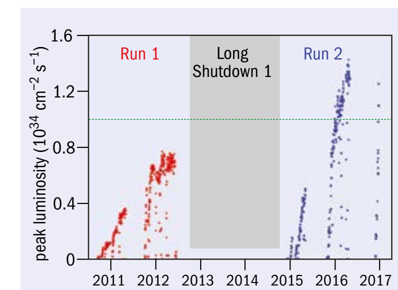
LHC NEWS

Physics resumes at LHC

First stable beams in the LHC were declared on 23 May, just 25 days after the first beam was injected and almost three weeks ahead of schedule. Since then, interleaved with physics operation and remaining commissioning activities, the LHC teams have been busy ramping up the intensity of the beams. During this procedure, the number of proton bunches circulating the machine is increased in a stepwise manner: beginning with three bunches per beam and going up to 12, 72, 300, 600, 900, 1200, 1800, 2400 and finally 2556 bunches per beam. To ensure that all systems work as they should, each step requires a minimum of 20 hours of stable-beam operation and that the machine is filled three times. As the *Courier* went to press on 28 June, 2556 bunches were circulating in the machine and already the experiments had clocked an integrated luminosity of around 5 fb^{-1}.

Another important procedure during the LHC restart is the so-called scrubbing run to condition the vacuum chamber, which took place in early June. Despite the ultra-high vacuum of the LHC beam pipe, residual gas molecules and electrons remain trapped on the walls of the chamber and can be liberated by the circulating beam, eventually heating the walls and destabilising the beam. Such "electron-cloud" effects can be reduced by repeatedly filling the LHC with closely spaced bunches, provoking intense electron clouds that gradually become less prone to produce further electrons.

The rapid and smooth restart of the LHC this year, which marks the continuation of Run 2 at a centre-of-mass energy of 13 TeV, is due to the excellent availability of the machine and its injector chain, and also the dedication of many specialists. The LHC is now ready to continue the intensity ramp for physics-data collection, with the ambitious goal of reaching an integrated luminosity of 45 fb^{-1} for 2017.



LHC Run 2 has seen a record increase in peak luminosity.

Sommaire en français

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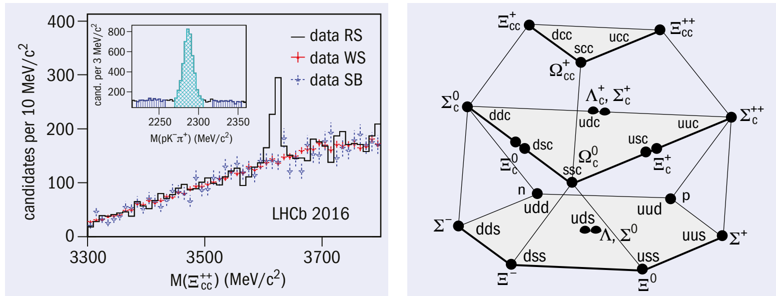
LHC EXPERIMENTS

LHCb discovers new baryon

The LHCb collaboration has discovered a new weakly decaying particle: a baryon called the Ξ_{cc}^{++}, which contains two charm quarks and an up quark. The discovery of the new particle, which was observed decaying to the final-state $\Lambda_c^+K^-\pi^+\pi^+$ and is predicted by the Standard Model, was presented at the European Physical Society conference in Venice on 6 July.

Although the quark model of hadrons predicts the existence of doubly heavy baryons – three-quark states that contain two heavy (c or b) quarks – this is the first time that such states have been observed unambiguously with overwhelming statistical significance (well in excess of 5σ with respect to background expectations). The properties of the newly discovered Ξ_{cc}^{++} baryon shed light on a long-standing puzzle surrounding the experimental status of doubly charmed baryons, opening an exciting new branch of investigation for LHCb.

The team scrutinised large high-purity samples of $\Lambda_c^+ \to pK^-\pi^+$ decays in LHC data recorded at 8 and 13 TeV in 2012 and 2016, respectively, and discovered an isolated narrow structure in the $\Lambda_c^+K^-\pi^+\pi^+$ mass spectrum (associating the Λ_c^+ baryon with further particles) at a mass of around 3620 MeV/c^2. After eliminating all known potential artificial sources, the collaboration concluded that the highly significant peak is a previously unobserved state. Corroboration that it is the weakly decaying Ξ_{cc}^{++} came from examining a subset of data in which the reconstructed baryons lived for a measurable period before decaying. Such a requirement eliminates all promptly decaying particles, leaving only long-lived ones that are the hallmark of weak transitions.



(Left) Mass spectrum recorded in 2016 showing the right-sign (RS) signal sample $\Xi_{cc}^{++}\to\Lambda_c^+K^-\pi^+\pi^+$ along with two control samples: sideband (SB) $\Lambda_c^+K^-\pi^+\pi^+$ candidates, and wrong-sign (WS) $\Lambda_c^+K^-\pi^+\pi^-$ candidates, each normalised to have the same area as the RS sample. The inset shows the Λ_c^+ mass distributions with the signal (cross-hatch) and sideband (vertical lines) regions. (Right) An illustration of the spin-1/2 baryon multiplet including light quarks and the charm quark, with the Ξ_{cc}^{++} located on the top floor.

Although the existence of baryons with valence-quark content ccu and ccd (corresponding to the Ξ_{cc}^{++} and its isospin partner Ξ_{cc}^{+}) is expected, the experimental status of these states has been controversial. In 2002, the SELEX collaboration at Fermilab in the US claimed the first observation of this class of particle by observing a significant peak of about 16 events at a mass of 3519±1 MeV/c^2 in the $\Lambda_c^+K^-\pi^+$ mass spectrum, which they identified as the closely related state Ξ_{cc}^{+}. Puzzlingly, the short lifetime (which was too small to be measured at SELEX) and the very large production rate of the state seemed not to match theoretical expectations for the Ξ_{cc}^{+}. Despite SELEX's confirmation of the observation in a second decay mode, all subsequent searches – including efforts at the FOCUS, BaBar and Belle experiments – failed to find evidence for doubly charmed baryons. That left both theorists and experimentalists awaiting a firm observation by a more powerful heavy-flavour detector such as LHCb. Although the new result from LHCb does not fully resolve the puzzle (with a mass difference of 103±2 MeV/c^2, LHCb's Ξ_{cc}^{++} and SELEX's Ξ_{cc}^{+} seem irreconcilable as isospin partners), the discovery is a crucial step to an empirical understanding of the nature of doubly heavy baryons.

Further reading

LHCb Collaboration 2017 LHCb-PAPER-2017-018.

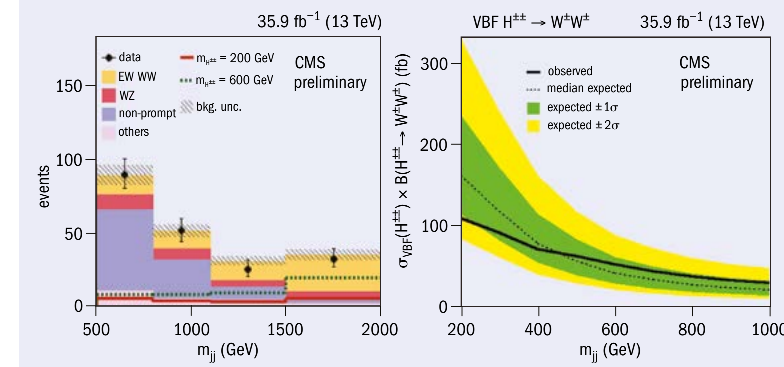
CMS observes production of same-sign W-boson pairs

The LHC was built with a guaranteed discovery: the ATLAS and CMS experiments would either find a Higgs boson, or it would discover new physics in vector boson scattering (VBS) at high energies. The discovery of a Higgs-like boson in July 2012 confirmed that the W and Z bosons acquire mass through the Higgs mechanism, but to determine whether the observed particle corresponds to the single Higgs boson expected in the Standard Model (SM), it is now paramount to precisely measure the Higgs boson's contributions to VBS. Since the behaviour of VBS amplitudes is sensitive to the way Higgs and vector bosons couple to one another and to the Higgs boson's mass, models of physics beyond the SM predict enhancements to VBS via modifications to the Higgs sector or from the presence of additional resonances.

A recent analysis by CMS aimed to identify events in which a W-boson pair is produced purely via the electroweak interaction. Requiring events to have a same-sign W-boson pair reduces the probability of production via the strong interaction, making it an ideal signature for VBS studies. The first experimental results on this final state were reported by ATLAS and CMS based on 20 fb^{-1} of LHC data collected in 2012 at an energy of 8 TeV, but were insufficient to claim an observation. The new study is based on 36 fb^{-1} of data collected in 2016 at 13 TeV. Events were selected by requiring they contain two leptons (electrons or muons) with the same electric charge, moderate missing transverse momentum, and two jets with a large rapidity separation and a large dijet mass. About 67 signal events were expected, with the dominant sources of background events coming from top quark–antiquark pairs and WZ boson pairs. The event yield of the signal process is then extracted using a 2D fit of the dijet and dilepton mass distributions (figure, left).

The new CMS study provides the first observation of the electroweak production of same-sign W-boson pairs in proton–proton collisions, with an observed significance of 5.5 standard deviations. The result does not point to physics beyond the SM: a cross-section of 3.8±0.7 fb is measured within the defined fiducial signal region, corresponding to 90±22% of the result expected. An excess of events could have been caused by the presence of a doubly charged Higgs boson that couples to W bosons, and the analysis sets upper bounds on the product of the cross-section and branching fraction for such particles (figure, right). Bounds on the structure of quartic vector-boson interactions are also obtained in the framework of dimension-eight effective field theory operators, and the measurements set 95% confidence-level limits that are up to six times more stringent than previous results.

This first observation of the purely electroweak production of same-sign W-boson pairs is an important milestone towards precision tests of VBS at the LHC, and there is much more to be learned from the rapidly growing data sets. Studies demonstrate that the High Luminosity LHC, due to enter operation in the early 2020s, should even allow a direct investigation of longitudinal W-boson scattering.



(Left) Distribution of the dijet mass in the signal region, with hatched bars including statistical and systematic uncertainties. Predictions for two scenarios of doubly charged Higgs boson production (red and green) are also shown. (Right) Expected and observed 95% confidence-level upper limits on the product of cross-section and branching fraction for doubly charged Higgs boson decays to a same-sign W-boson pair.

Further reading

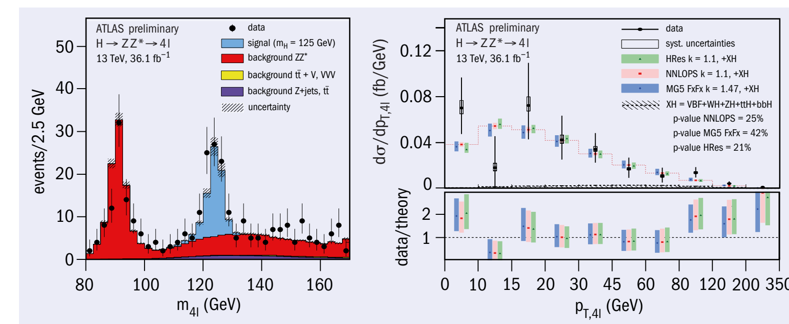
CMS Collaboration 2017 CMS-PAS-SMP-17-004.
CMS Collaboration 2017 CMS-PAS-HIG-16-027.
CMS Collaboration 2017 CMS-PAS-SMP-14-008.

ATLAS probes Higgs boson at 13 TeV

The ATLAS collaboration has released new results on measurements of the properties of the Higgs boson using the full LHC proton–proton collision data set collected at a centre-of-mass energy of 13 TeV in 2015 and 2016, corresponding to an integrated luminosity of 36.1 fb^{-1}.

One of the most sensitive measurement channels involves Higgs boson decays via two Z bosons to four leptons (two pairs of oppositely charged electrons or muons). Although only occurring in about one in every 8000 Higgs decays, it gives the cleanest signature of all the Higgs decay modes.

Using this channel, ATLAS measured both the inclusive and differential cross-sections for Higgs boson production. Although these have been measured before at lower LHC collision energy, the increased integrated luminosity and larger cross-section compared to LHC Run 1 allows their magnitudes to be determined with increased precision. In total, around 70 Higgs boson to four-lepton events were measured with a fit to the invariant mass distribution, allowing the inclusive cross-section to be measured with an accuracy of about 16%.



(Left) The invariant mass spectrum measured in the four-lepton final state with the expected SM background and signal superimposed. (Right) The measured differential cross-section for the transverse momentum ($p_{T,4l}$) of the Higgs boson, compared to theoretical predictions.

Candidate Higgs boson events were corrected for detector measurement effects and classified according to their kinematic properties to measure differential production cross-sections. Among these, the measurement of the momentum of the Higgs boson transverse to the beam axis probes different Higgs boson production mechanisms. By measuring the number and properties of jets produced in these events, Higgs boson production via the fusion of two gluons was studied. The measured inclusive and differential cross-sections were found to be in agreement with the Standard Model (SM) predictions. The results were used to constrain possible anomalous Higgs boson interactions with SM particles.

Further reading

ATLAS Collaboration 2017 ATLAS-CONF-2017-032.

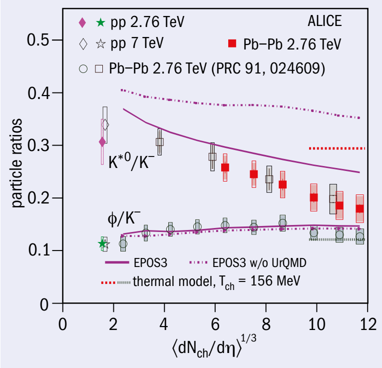
***Les physiciens des particules du monde entier sont invités** à apporter leurs contributions au CERN Courier, en français ou en anglais. Les articles retenus seront publiés dans la langue d'origine. Si vous souhaitez proposer un article, faites part de vos suggestions à la rédaction à l'adresse cern.courier@cern.ch.*

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.

ALICE zooms in on evolution of the quark–gluon plasma

The precise particle-identification and momentum-measurement capabilities of the ALICE experiment allow researchers to reconstruct a variety of short-lived particles or resonances in heavy-ion collisions. These serve as a probe for in-medium effects during the last stages of evolution of the quark–gluon plasma (QGP). Recently, the ALICE collaboration has made a precise measurement of the yields (number of particles per event) of two such resonances: $K^*(892)^0$ and $\phi(1020)$. Both have similar masses and the same spin, and both are neutral strange mesons, yet their lifetimes differ by a factor of 10 (4.16±0.05 fm/c for K^{*0}, and 46.3±0.4 fm/c for ϕ).

The shorter lifetime of the K^{*0} means that it decays within the medium, enabling its decay products (π and K) to re-scatter with other hadrons. This would be expected to inhibit the reconstruction of the parent K^{*0}, but the π and K in the medium may also scatter into a K^{*0} resonance state, and the interplay of these two competing re-scattering and regeneration processes becomes relevant for determining the K^{*0} yield. The processes depend on the time interval between chemical freeze-out (vanishing inelastic collisions) and kinetic freeze-out (vanishing elastic collisions), in addition to the source size and the interaction cross-sections of the daughter hadrons. In contrast, due to the longer lifetime of the ϕ meson, both the re-scattering and regeneration effects are expected to be negligible.



Ratio of K^{*0} and ϕ yields to charged-kaon yields at midrapidity for Pb–Pb and pp collisions as a function of charged-particle pseudorapidity density at midrapidity $(dN_{ch}/d\eta)^{1/3}$, which is related to the final-state freeze-out geometry of the system. Also shown are corresponding results from models with and without re-scattering.

Using lead–lead collision data recorded at an energy of 2.76 TeV, ALICE observed that the ratio K^{*0}/K^- decreases as a function of system size (see figure). In small impact-parameter collisions, the ratio is significantly less than in proton–proton collisions and models without re-scattering effects. In contrast, no such suppression was observed in the ϕ/K^- ratio. This measurement thus suggests the existence of re-scattering effects on resonances in the last stages of heavy-ion collisions at LHC energies. Furthermore, the suppression of K^{*0} yields can be used to obtain the time difference between the chemical and the kinetic freeze-out of the system.

On the other hand, at higher momenta ($p_T > 8$ GeV/c), these resonances were suppressed with respect to proton–proton collisions by similar amounts. The magnitude of this suppression for K^{*0} and ϕ mesons was also found to be similar to the suppression for pions, kaons, protons and D mesons. The striking independence of this suppression on particle mass, baryon number and the quark-flavour content of the hadron puts a stringent constraint on models dealing with particle-production mechanisms, fragmentation processes and parton energy loss in the QGP medium.

In future, it will be important to perform such measurements for high-multiplicity events in pp collisions at the LHC.

● Further reading

ALICE Collaboration 2017 *Phys. Rev. C.* **95** 064606.

Dark matter

XENON1T releases first data

The XENON1T detector and the three-storey building next door containing auxiliary equipment.

Researchers from the XENON1T dark-matter experiment at Gran Sasso National Laboratory in Italy reported their first results at the 13th Patras Workshop on Axions, WIMPs and WISPs, held in Thessaloniki from 15–19 May (see p51). XENON1T is the first tonne-scale detector of its kind and is designed to search for WIMP dark matter by measuring nuclear recoils from WIMP–nucleus scattering. Continuing the programme of the previous XENON10 and XENON100 detectors, the new apparatus contains 3200 kg of ultra-pure liquid xenon (LXe) – 20 times more than its predecessor – in a dual-phase xenon time projection chamber (TPC) to detect nuclear recoils. The TPC encloses about 2000 kg of LXe, while another 1200 kg provides additional shielding.

The experiment started collecting data in November 2016. A blind search based on 34.2 live days of data acquired until January 2017, when earthquakes in the region temporarily suspended the run, revealed the data to be consistent with the background-only hypothesis. This allowed the collaboration to derive the most stringent exclusion limits on the spin-independent WIMP–nucleon interaction cross-section for WIMP masses above 10 GeV/c^2, with a minimum of 7.7×10^{-47} cm^2 for 35 GeV/c^2 WIMPs at 90% confidence level.

These first results demonstrate that XENON1T has the lowest low-energy background level ever achieved by a dark-matter experiment, with the intrinsic background from krypton and radon reduced to unprecedented low levels. The sensitivity of XENON1T will continue to improve as the experiment records data until the end of 2018, when the collaboration plans to upgrade to a larger TPC due to come online by 2019. Several other experiments, such as PANDA-X and LUX-ZEPLIN, are also competing for the first WIMP detection.

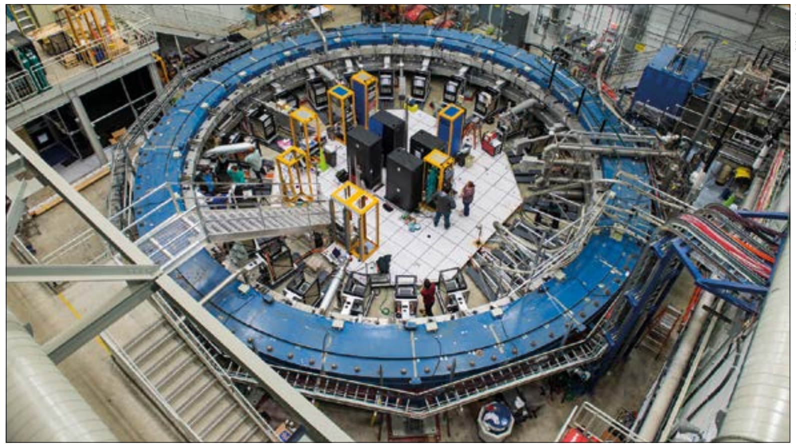
"With our experiment working so beautifully, even exceeding our expectations, it is really exciting to have data in hand to further explore one of the most exciting secrets we have in physics: the nature of dark matter," says XENON spokesperson Elena Aprile of Columbia University in the US.

● Further reading

XENON Collaboration 2017 arXiv:1705.06655.

Muon magnetic moment

First beam at Muon g-2



The electromagnet for Fermilab's Muon g-2 experiment, which involves more than 150 scientists and engineers from nine countries.

The Muon g-2 experiment at Fermilab has begun its three-year-long campaign to measure the magnetic moment of the muon with unprecedented precision. On 31 May, a beam of muons was fired into the experiment's 14 m-diameter storage ring, where powerful electromagnetic fields cause the magnetic moment, or spin, of individual muons to precess. The last time this experiment was performed, using the same electromagnet at Brookhaven National Laboratory in the late 1990s and early 2000s, the result disagreed with predictions by more than three standard deviations. This hinted at the presence of previously unknown particles or forces affecting the muon's properties, and motivated further measurements to check the result.

Sixteen years later, the reincarnated Muon g-2 experiment will make use of Fermilab's intense muon beams to definitively answer the questions raised by the Brookhaven experiment. It turned out to be 10 times cheaper to move the apparatus to Fermilab than it would have cost to build a new machine at Brookhaven, and the large, fragile superconducting magnet was transported in one piece from Long Island to the suburbs of Chicago in the summer of 2013.

Since it arrived, the Fermilab team reassembled the magnet and spent a year adjusting or "shimming" the uniformity of its field. The field created by the g-2 magnet is now three times more uniform than the one it created at Brookhaven. In the past year, the team has worked around the clock to install detectors, build a control room and prepare for first beam. The work has included: the creation of a new beamline to deliver a pure beam of muons; instrumentation to measure the magnetic field; and entirely new instrumentation to measure the muon's spin-precession signal.

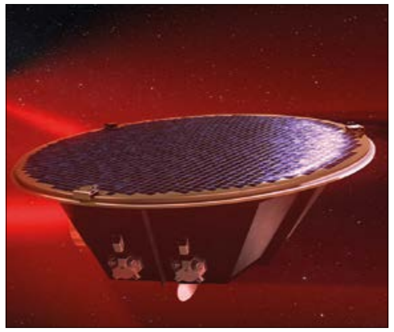
Over the next few weeks the Muon g-2 team will test the equipment, with science-quality data expected later in the year. The experiment aims to achieve a precision on the anomalous magnetic moment of the muon of 0.14 parts per million, compared to around 0.54 parts per million previously. If the inconsistency with theory remains, it could indicate that the Standard Model of particle physics is in need of revision.

Gravitational waves

ESA gives green light for LISA

On 20 June the European Space Agency (ESA) gave the official go-ahead for the Laser Interferometer Space Antenna (LISA), which will comprise a trio of satellites to detect gravitational waves in space. LISA is the third mission in ESA's Cosmic Vision plan, set to last for the next two decades, and has been given a launch date of 2034.

Predicted a century ago by general relativity, gravitational waves are vibrations of space–time that were first detected by the ground-based Laser Interferometer Gravitational-Wave Observatory (LIGO) in September 2015. While upgrades to LIGO and other ground-based observatories are planned, LISA will access a much lower-frequency region of the gravitational-wave universe. Three craft, separated by 2.5 M km in a triangular formation, will follow Earth in its orbit around the Sun, waiting to be distorted by a fractional amount by a passing gravitational wave.



The LISA detector will use enormous interferometer arms to maximise sensitivity, which is only possible in space.

Although highly challenging experimentally, a LISA test mission called Pathfinder has recently demonstrated key technologies needed to detect gravitational waves from space (*CERN Courier* January/February 2017 p34). These include free-falling test masses linked by lasers and isolated from all external and internal forces except gravity. LISA Pathfinder concluded its pioneering mission at the end of June, as LISA enters a more detailed phase of study. Following ESA's selection, the design and costing of the LISA mission can be completed. The project will then be proposed for "adoption" before construction begins.

Following the first and second detections of gravitational waves by LIGO in September and December 2015, on 1 June the collaboration announced the detection of a third event (*Phys. Rev. Lett.* **118** 221101). Like the previous two, it is thought that "GW170104" – the signal for which arrived on Earth on 4 January – was produced when two black holes merged into a larger one billions of years ago.

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HL-LHC

LHC luminosity upgrade accelerates

CERN has recently implemented two important steps towards the High Luminosity LHC (HL-LHC) – an upgrade that will increase the intensity of the LHC's collisions significantly from the early 2020s. Preparing CERN's existing accelerator complex to cope with more intense proton beams presents several challenges, in particular concerning the system that injects protons into the LHC.

At a ceremony on 9 May, a major new linear accelerator, Linac 4, was inaugurated. Replacing Linac 2, which had been in service since 1978, it is CERN's newest accelerator acquisition since the LHC and is due to feed the accelerator complex with higher-energy particle beams. After an extensive testing period, Linac 4 will be connected to the existing infrastructure during the long technical shutdown in 2019/2020.

To cope with the higher-intensity and higher-energy beams emerging from Linac 4, the Proton Synchrotron Booster (PSB), which is the second accelerator of the LHC injector chain, will be completely overhauled during that same period. At the beginning of June, the first radio-frequency cavity of the new PSB acceleration system was completed, with a further 27 under assembly. The new cavities are based on a composite magnetic material called FINEMET developed by Hitachi Metals, which allows them to operate with a large bandwidth and means that a single cavity can cover all necessary frequency bands. The PSB cavity project was launched in 2012 in collaboration with KEK in Japan, and involved intensive testing at CERN. KEK contributed a substantial fraction of the FINEMET cores and shared its experience with similar technology.

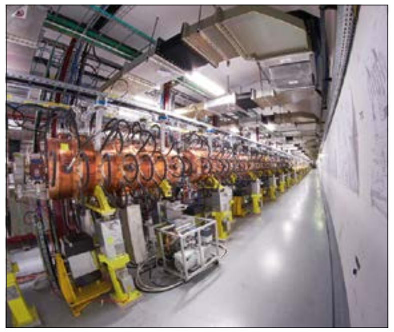


Image credits: M Brice

(Left) A view of the PI-Mode Structure (PIMS) cavities, which will accelerate the Linac 4 beam from 100 to 160 MeV. (Right) Mauro Paoluzzi, project leader for the PSB RF overhaul, with one of the FINEMET cavities that will allow more intense beams.

CERN Neutrino Platform

Neutrino detectors on the move

On 12 June, two large detector modules for the ICARUS experiment were loaded onto trucks at CERN to begin a six-week journey to Fermilab in the US. ICARUS will form part of Fermilab's short-baseline neutrino programme, which aims to make detailed measurements of neutrino interactions and search for eV-scale sterile neutrinos (*CERN Courier* June 2017 p25).

Based on advanced liquid-argon time projection technology, ICARUS began its life under a mountain at the Gran Sasso National Laboratory in Italy in 2010, recording data from neutrino beams sent from CERN. Since 2014, it has been at CERN undergoing an upgrade and refurbishment at the CERN Neutrino Platform (*CERN Courier* July/August 2016 p21). It left CERN in two parts by road and boarded a boat on the Rhine to a port in Antwerp, Belgium, where it was loaded onto a ship. As the *Courier* went to press, ICARUS was already heading across the Atlantic to Fermilab via the Great Lakes, equipped with a GPS unit that allows its progress to be tracked in real time (icarustrip.fnal.gov).

Just two days after ICARUS left CERN, another key component of the CERN Neutrino Platform was on the move, albeit on a smaller lorry. Baby MIND, a 75 tonne prototype for a magnetised iron neutrino detector that will precisely identify and track muons, was moved from its construction site in building 180 to the East Hall of the Proton Synchrotron. Following commissioning and full characterisation in the T9 test beam, at the end of July Baby MIND will be transported to Japan to be part of the WAGASCI experiment at JPARC, where it will contribute to a better understanding of neutrino interactions for the T2K experiment.

N Gonzalez and J Ordan, Julien Marius

E Noah

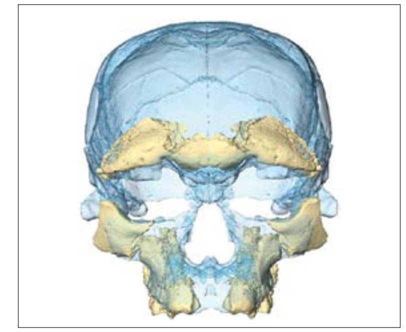
ICARUS (above) on its departure day, and a section of Baby MIND (left) being moved to the test-beam area.

Sciencewatch

Compiled by John Swain, Northeastern University

Human origins pushed back

New remains found in a Moroccan mine could radically revise the current idea that humans originated in East Africa some 200,000 years ago. Jean-Jacques Hublin of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, and colleagues analysed bones of at least five humans found at Jebel Irhoud, a barite mine 100 km west of Marrakesh. Sharpened flint tools, gazelle bones and lumps of charcoal were also found. These are the oldest known bones of modern humans, with an average age determined from thermoluminescent dating of 315±34 thousand years, and the ages determined are also consistent with faunal and microfaunal assemblages. This pushes back the origin of humans by an amazing 100,000 years, while also suggesting new geographical origins.



A superimposition of bone fragments from two individuals, shown in beige and light blue, represents how the skulls of our earliest ancestors might have looked.

Further reading
J-J Hublin *et al.* 2017 *Nature* **546** 289.
D Richter *et al.* 2017 *Nature* **546** 293.

GR weighs a white dwarf

The detection in 1919 of starlight that had been deflected by the Sun was one of the first convincing proofs of Einstein's general theory of relativity. Now, Kailash Sahu of the Space Telescope Science Institute in Baltimore and colleagues have used the Hubble Space Telescope to measure the analogous bending of light around the white-dwarf Stein 2051B, allowing them to calculate its mass to be 0.675±0.051 solar masses. In addition to the first measurement of the deflection of starlight by a star other than the Sun, the work provides valuable verification of the relation between the mass of a white dwarf and its radius.

Further reading
K Sahu *et al.* 2017 *Science* **356** 1046.

Solid-state refrigerators

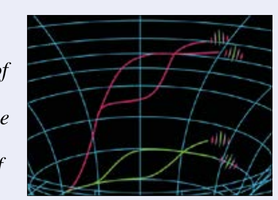
Harmful chloroflurocarbons (CFCs) in refrigeration devices could be replaced with solid refrigerants that are more efficient and environmentally benign. Pedro Jorge von Ranke of the Universidade do Estado do Rio de Janeiro has shown that materials called spin-crossover systems have pressure-induced changes in entropy between low-spin and high-spin states that are large enough to use for a practical cooling cycle. These giant "barocaloric" effects are analogous to magnetocaloric effects, but use pressure instead of magnetic fields.

Further reading
P von Ranke 2017 *App. Phys. Lett.* **110** 181909.

Tidal phase shift measured

In what is arguably the first manifestation of gravity in a quantum-mechanical system, physicists have observed the tidal phase shift in an atom interferometer. Peter Asenbaum of Stanford University and colleagues used a dual light-pulse rubidium atom interferometer, in which a macroscopic spatial superposition state acts as a nonlocal probe of space–time. Space–time curvature induces tidal forces on the wave function of a single quantum system, and the team was able to measure a phase shift associated with such tidal forces. Additionally, the dual atom interferometer works as a gradiometer for precise gravitational measurements and could be used for measurements of the gravitational constant or the gravitational Aharonov–Bohm effect.

Further reading
P Asenbaum *et al.* 2017 *Phys. Rev. Lett.* **118** 183602.



The team measured the effect of the tidal force on the wave function of individual particles by varying the separation between the two arms of the sensor interferometer (green) while keeping the distance to the reference interferometer (pink) constant. (Image credit: APS.)

Humans smell better

According to neurobiologist John McGann of Rutgers University in the US, poor human olfaction is a 19th century myth. The idea that humans have a relatively poor sense of smell, he argues, did not come from empirical studies of human olfaction but from a 19th century anatomist's idea that human free will required a reduction in the brain's olfactory bulb. In reality, our olfactory bulbs are quite large and have similar numbers of neurons to those of other mammals. In fact we are able to track odour trails, and are even more sensitive than rodents and dogs to some odours.

Further reading
J McGann 2017 *Science* **356** 597.

Ancient carvings and comets

It has long been speculated that a comet strike caused a sudden drop in the Earth's temperature during a period called the Younger Dryas. Now, researchers at the University of Edinburgh have found support for this view. They matched carvings at the Gobekli Tepe temple site in Turkey to star asterisms, and found that the famous "Vulture Stone", dated 10,950±250 BC, fits well with the Younger Dryas event estimated at 10,890 BC. The date of the strike coincides with the emergence of agriculture and the beginnings of modern civilisation.

Further reading
M Sweatman and D Tsikritsis 2017 *Mediterranean Archaeology and Archaeometry* **17** 233.

Astrowatch

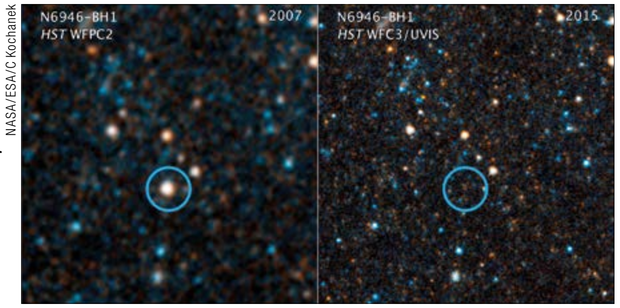
Compiled by Merlin Kole, Department of Particle Physics, University of Geneva

Astronomers spot first failed supernova

Massive stars are traditionally expected to end their life cycle by triggering a supernova, a violent event in which the stellar core collapses into a neutron star, potentially followed by a further collapse into a black hole. During this process, a shock wave ejects large amounts of material from the star into interstellar space with large velocities, producing heavy elements in the process, while the supernova outshines all the stars in its host galaxy combined.

In the past few years, however, there has been mounting evidence that not all massive-star deaths are accompanied by these catastrophic events. Instead, it seems that for some stars only a small part of their outer layers is ejected before the rest of the volume collapses into a massive black hole. For instance, there are hints that the birth rate and supernova rate of massive stars do not match. Furthermore, results from the LIGO gravitational-wave observatory in the US indicate the existence of black holes with masses more than 30 times that of the Sun, which is easier to explain if stars can collapse without a large explosion.

Motivated by this indirect evidence, researchers from Ohio State University began a search for stars that quietly form a black hole without triggering a supernova. Using the Large Binocular Telescope (LBT) in Arizona, in 2015 the team identified its first candidate. The star, called N6946-BH1, was approximately 25 times more massive than the Sun and lived in the Fireworks galaxy, which is known for hosting a large number of supernovae. Previously presenting a stable luminosity, the star was seen to become brighter, although not at the level expected for a supernova, during 2009, before completely disappearing in optical wavelengths in 2010 (see image).



This pair of visible-light and near-infrared photos from the Hubble Space Telescope shows the giant star N6946-BH1 before (left) and after (right) it vanished out of sight, likely forming a black hole.

The lack of emission observed by the LBT triggered follow-up searches for the star, both using the Hubble Space Telescope (HST) and the Spitzer Space Telescope (SST). While the HST did not find signs of the star in the optical wavelength, the SST did observe infrared emission. A careful analysis of the data disfavoured alternative explanations such as a large dust cloud obscuring the optical emission from the star, and the infrared data were also shown to be compatible with emission from remaining matter falling into a black hole.

If the star did indeed directly collapse into a black hole, as these findings suggest, the in-falling matter is expected to radiate in the X-ray region. The team is therefore waiting for observations from the space-based Chandra X-ray Observatory to search for this emission.

If confirmed in X-ray data, this result would be the first measurement of the birth of a black hole and the first measurement of a failed supernova. The results would explain why we observe less supernovae than expected and could reveal the origin of the massive black holes responsible for the gravitational waves seen by LIGO, in addition to having implications for the production of heavy elements in the universe.

Further reading

S M Adams *et al.* 2017 *Mon. Not. R. Astron. Soc.* **468** 4968.

Picture of the month

This image shows Simeis 147, more popularly known as the Spaghetti Nebula. It is a remnant of a supernova estimated to have taken place 40,000 years ago and measures roughly 150 light-years across at an estimated distance of 3000 light-years from Earth. This translates to an angular size of almost three degrees, or six full moons, on the sky. The composite image includes data taken using filters, which enhance the reddish emission from ionised hydrogen atoms in the shock waves. The remnant was found to also emit photons with energies in the GeV range by the Fermi-LAT satellite. These gamma rays, thought to originate from neutral pion decay, are not associated with the neutron star also thought to populate the remnant, but rather with the red spaghetti-like lines of the remnant.

Europe enters the extreme X-ray era

The European X-ray Free-Electron Laser in Germany is about to open for user experiments. The culmination of a worldwide effort, the facility will eventually fire up to 27,000 pulses of intense X-rays per second to image electronic, chemical and biological processes in unprecedented detail.

The past few decades have witnessed an explosion in X-ray sources and techniques, impacting science and technology significantly. Large synchrotron X-ray facilities around the world based on advanced storage rings and X-ray optics are used daily by thousands of scientists across numerous disciplines. From the shelf life of washing detergents to the efficiency of fuel-injection systems, and from the latest pharmaceuticals to the chemical composition of archaeological remains, highly focused and brilliant beams of X-rays allow researchers to characterise materials over an enormous range of length and timescales, and therefore link the microscopic behaviour of a system with its bulk properties.

So-called third-generation light sources based on synchrotrons produce stable beams of X-rays over a wide range of photon energies and beam parameters. The availability of more intense, shorter and more coherent X-ray pulses opens even further scientific opportunities, such as making high-resolution movies of chemical reactions or providing industry with real-time nanoscale imaging of working devices. This boils down to maximising a parameter called peak brilliance. While accelerator physicists have made enormous strides in increasing the peak brilliance of synchrotrons, this quantity experienced a leap forward by many orders of magnitude when the first free-electron lasers (FELs) started operating in the X-ray range more than a decade ago.

FLASH, the soft-X-ray FEL at DESY in Hamburg, was ▷

A 500 m-long "drift section" in the XTD9 tunnel used to separate the beam for two of the European XFEL's scientific end stations. (Image credit: European XFEL.)

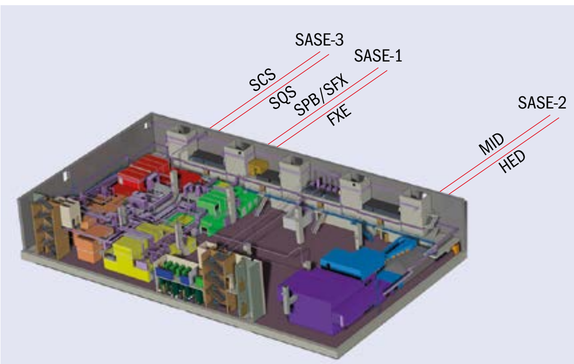


Fig. 1. (Top) The three tunnel distribution buildings XHE2–4 and the European XFEL headquarters (XHQ) with the experimental hall located approximately 20 m underground. A system of photon-distribution tunnels (red) shares the electron pulses among the different undulators that will provide tunable photon energies in the soft- and hard-X-ray regimes. (Above left) Model of the 50 × 90 m² underground experimental hall showing instrument hutches in different colours. Six instruments share three SASE beamlines, and the hall and tunnel areas allow for the installation of two additional SASE undulators and up to six additional instruments. (Above right) A few of the 35 planar undulator segments, each 5 m long with a magnetic period of 40 mm, installed in the SASE-1 branch of the European XFEL. A phase shifter between each undulator segment allows fine-tuning of the SASE process.

inaugurated in 2005 and marked the beginning of this new epoch in X-ray science. Based on superconducting accelerating structures developed initially for a linear collider for particle physics (see p25), it provided flashes of VUV radiation with peak brilliances almost 10 orders of magnitude higher than any storage-ring-based source in the same wavelength range. The unprecedented peak power of the beam immediately led to groundbreaking new research in physics, chemistry and biology. But importantly, FLASH also demonstrated that the amplification scheme responsible for the huge gain of FELs – Self Amplified Spontaneous Emission (SASE) – was feasible at short wavelengths and could likely be extended to the hard-X-ray regime.

The first hard-X-ray FEL to enter operation based on the SASE principle was the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory in California, which obtained first light in 2009 using a modified version of the old SLAC linac and operates at X-ray energies up to around 11 keV. Since then, several facilities have been inaugurated or are close to start-up: SACLA in Japan, Pohang FEL in South Korea, and Swiss-FEL in Switzerland. The European X-ray Free-Electron Laser (European XFEL) in Schenefeld-Hamburg, Germany, marks a further step-change in X-ray science, promising to produce the brightest beams with the highest photon energies and the highest repetition rates. Construction of the €1.2 billion facility began in January 2009 funded by 11 countries: Denmark, France, Germany, Hungary, Italy, Poland, Russia, Slovakia, Spain, Sweden and Switzerland, with Germany (58%) and Russia (27%) as the largest contributors. It is expected that the UK will join the European XFEL in 2017.

The European XFEL extends over a distance of 3.4 km in underground tunnels (figure 1). It begins with the electron injector at DESY in Bahrenfeld-Hamburg, which produces and injects electrons into a 2 km-long superconducting linear accelerator where the desired electron energy (up to 17.5 GeV) is achieved. Exiting the linac, electrons are then rapidly deflected in an undulating left–right pattern by traversing a periodic array of magnets called an undulator (figure 1, bottom right), causing the electrons to emit intense beams of X-ray photons. X-rays emerging from the undulator, via 1 km-long photon-transport tunnels equipped with various X-ray optics elements, finally arrive at the European XFEL headquarters in Schenefeld where the experiments will take place.

In addition to the development of the electron linac, which was commissioned earlier this year and involved a major effort by DESY in collaboration with numerous other accelerator facilities over the past decade (see p25), the European XFEL has driven the development of both undulator technology and advanced X-ray optics. This multinational and multidisciplinary effort now opens perspectives for novel scientific experiments. When fully commissioned, towards the end of 2018, the facility will deliver 4000 hours of accelerator time per year for user experiments that are approved via external peer review.

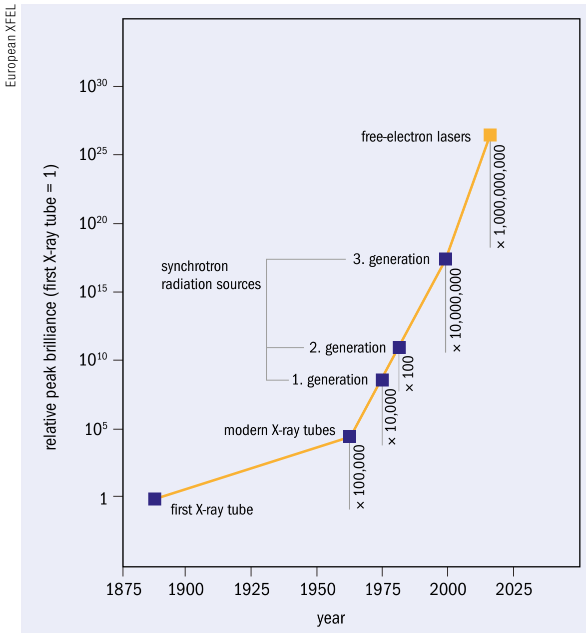
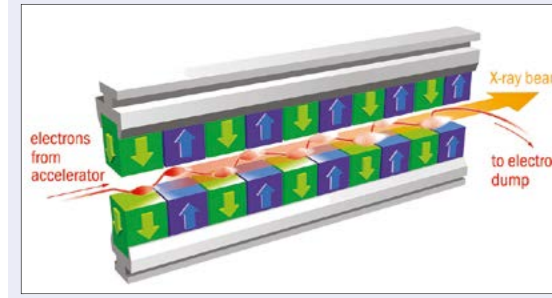


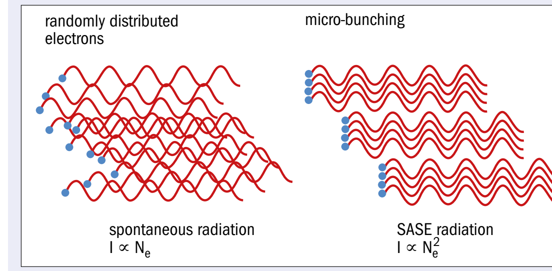
Fig. 2. The peak brilliance of VUV and X-ray sources has grown tremendously since the discovery of X-rays in 1895. The increase from storage-ring-based sources (synchrotrons) to linac-driven X-ray lasers is due to the extremely short and intense light pulses generated by SASE when a relativistic electron beam of small emittance passes through a very long magnetic array known as an undulator.

Manipulating X-rays

Synchrotron radiation was first detected experimentally at Cornell in 1947, and the first generation of synchrotron-radiation users were termed "parasitic" because they made use of X-rays produced as a byproduct of particle-physics experiments. Dedicated "second-generation" X-ray sources were established in the early 1970s, while much more brilliant "third-generation" sources based on devices called undulators started to appear in the early 1990s (figure 2). The SASE technology underpinning XFELs, which followed from work undertaken in the mid-1960s, ensures that the produced X-rays are much more intense and more coherent that those emitted by storage rings (see SASE panel above). Like the light coming from an optical laser, the X-rays generated by SASE are almost 100% transversely coherent compared to less than one per cent for third-generation synchrotrons, indicating that the radiation is an almost perfect plane wave. Even though the longitudinal-coherence length is not comparable to that of a single-mode optical laser, the use of the term "X-ray laser" is clearly justified ▷

The principle of SASE





Self-Amplified Spontaneous Emission (SASE), the underlying principle of X-ray free-electron lasers, is based on the interaction between a relativistic electron beam and the radiation emitted by the electrons as they are accelerated through a long alternating magnetic undulator array (see image top). If the undulator is short, on the order of a few metres, and the undulating path is well defined with a small amplitude, the radiation emitted by one electron adds up coherently at one particular wavelength as it travels through the undulator. Hence, the intensity is proportional to N_p^2, where N_p is the number of undulator periods (typically around 100). This is the regular undulator radiation generated at third-generation synchrotron sources such as the ESRF in France or APS in the US, and also at the next generation of diffraction-limited storage rings, such as MAX IV in Sweden. (Image credit: European XFEL.)

On the other hand, if the undulator is very long, the interactions between the electrons and the radiation field that builds up will eventually lead to micro-bunching of the electron beam into coherent packages that radiate in phase (see image above). This results in a huge amplification (lasing) of emitted intensity as it becomes proportional to N_e^2, where N_e is the number of electrons emitting in phase within the co-operation length (typically 10^6, or more). The hard-X-ray undulators of the European XFEL have magnetic lengths of 175 m in order to ensure that SASE works over a wide range of photon energies and electron-beam parameters. High electron energy, small energy spread and a small emittance (the product of beam size and divergence) are crucial for SASE to work in the X-ray range. Together with the requirement of very long undulators, it favours the use of linac sources, instead of storage rings, for X-ray lasers.

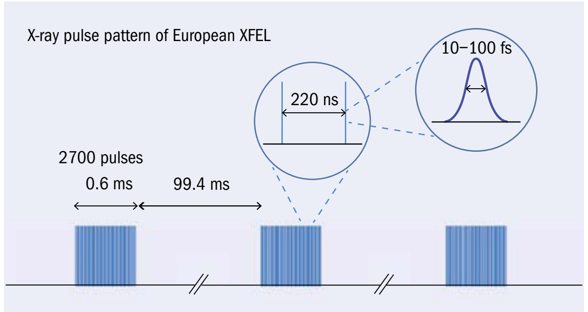


Fig. 3. The European XFEL linac delivers trains of electron pulses to the undulators, which produce an equivalent pattern of SASE X-ray pulses. The trains last 600 µs and contain up to 2700 pulses each, approximately 10–100 fs in duration, corresponding to a length of just 3–30 µm. With an output of 10 trains per second, i.e. a maximum of 27,000 pulses per second, the European XFEL can generate more than 100 times the average power of any other FEL worldwide.

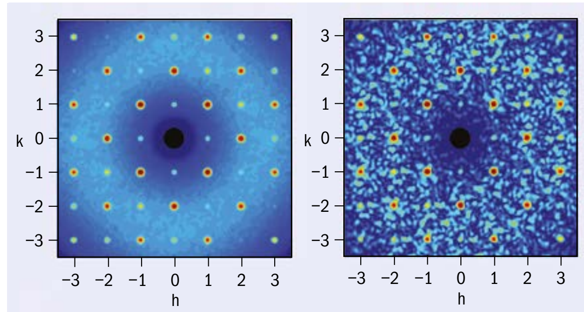


Fig. 4. Simulation of X-ray diffraction from a crystal with an acoustic phonon distorting the lattice. A short coherent SASE pulse provides a snapshot of the atomic positions, resulting in "speckle" decorating reciprocal space between the Bragg peaks (right). In a time-averaged incoherent X-ray-scattering experiment the speckles that reflect the exact positional disorder of the atoms disappear and only a broad diffuse scattering background remains (left).

for facilities such as the European XFEL.

A major challenge with X-ray lasers is to develop the mirrors, monochromators and other optical components that enable high-energy X-rays to be manipulated and their coherence to be preserved. Compared with the visible light emerging from a standard red helium-neon laser, which has a wavelength of 632 nm, the typical wavelength of hard X-rays is around 0.1 nm. Consequently, X-ray laser light is up to 6000 times more sensitive to distortions in the optics. On the other hand, X-ray mirrors work at extremely small grazing incidence angles (typically around 0.1° for hard X-rays at the European XFEL) because the interaction between X-rays and matter is so weak. This reduces the sensitivity to profile distortions and makes errors of up to 2 nm tolerable on a 1 m-long X-ray mirror, before the reflected X-ray wavefront becomes noticeably affected. Still, these requirements on profile errors are extremely high – about 10 times more stringent than for the Hubble Space Telescope mirror, for example.

The technology to produce these ultra-flat X-ray mirrors was only developed in recent years in Japan and Europe. It is based on a process called deterministic polishing, in which material is removed atomic layer by atomic layer according to a very precisely measured map of the initial profile's deviations from an ideal shape. After years of development and many months of deterministic polishing iterations, the first 95 cm-long silicon X-ray mirror fulfilling the tight specifications of the European XFEL was completed in March 2016, with 10 more mirrors of similar quality following shortly thereafter. In the final configuration, 27 of these extremely precise mirrors will be used to steer the X-ray laser beam along the photon-transport tunnels to all the scientific instruments.

Managing the large heat loads on the European XFEL mirrors is a major challenge. To remove the heat generated by the X-ray laser beam without distorting the highly sensitive mirrors, a liquid-metal film is used to couple the mirror to a water-cooling system in a tension- and vibration-free fashion. Another mirror system will be cooled to a temperature of around 100 K, at which the thermal-expansion coefficient of silicon is close to zero. This solution, which is vital to deal with the high repetition rate of the European XFEL, is often employed for smaller silicon crystals acting as crystal monochromators but is rarely necessary for large mirror bodies where the grazing-incidence geometry spreads the heat over a large area.

Indeed, the SASE pulses have potentially devastating power – especially close to the sample where the beam may be focused to small dimensions. A typical SASE X-ray pulse of 100 fs duration contains about 2 mJ of thermal X-ray energy (corresponding to 10^{12} photons at 12 keV photon energy), which means that a copper beam-stop placed close behind the sample would be heated to a temperature of several 100,000 °C and could therefore be evaporated (along with the sample) from just one pulse. While this is not necessarily a problem for samples that can be replaced via advanced injection schemes and where data can be collected before destruction takes place, it could shorten the lifetime of slits, attenuators, windows and other standard beamline components. The solution is to intersect the beam only where it has a larger size and to use only light elements that absorb less X-ray energy per atom. Still, stopping the X-ray laser beam remains a challenge at the European XFEL, with up to 2700 pulses in a 600 µs pulse train (figure 3). Indeed, the entire layout of the photon-distribution system was adapted to counteract this damaging effect of the X-ray laser beam, and a facility-wide machine-protection system limits the pulse-train length to a safe limit, depending on the optical configuration. Since a misguided X-ray laser beam can quickly drill through the stainless-steel pipes of the vacuum system, diamond plates are positioned around the beam trajectory and will light up if hit by X-rays, triggering a dump of the electron beam.

The facility will deliver 4000 hours of accelerator time per year for user experiments.

The business end of things

At the European XFEL, the generation of X-ray beams is largely "behind the scenes". The scientific interest in XFEL experiments stems from the ability to deliver around 10^{12} X-ray photons in one ultrafast pulse (with a duration in the range 10–100 fs) and with a high degree of coherence. Performing experiments within such short pulses allows users to generate ultrafast snapshots of dynamics that would be smeared out with longer exposure times and give rise to diffuse scattering. Combined with spectroscopic information, a complete picture of atomic motion and molecular rearrangements, as well as the charge and spin states and their dynamics, can be built up. This leads to the notion of a "molecular movie", in which the dynamics are triggered by an external optical laser excitation (acting as an optical pump) and the response of a molecule is monitored by ultrafast X-ray scattering and spectroscopy (X-ray probe). Pump-probe experiments are typically ensemble-averaged measurements of many molecules that are randomly aligned with respect to each other and not distinguishable within the scattering volume. The power and coherence of the European XFEL beams will allow such investigations with unprecedented resolution in time and space compared to today's best synchrotrons.

In particular, the coherence of the European XFEL beam allows users to distinguish features beyond those arising from average properties. These features are encoded in the scattering images as grainy regions of varying intensity called speckle, which results from the self-interference of the scattered beam and can be exploited to obtain higher spatial resolution than is possible in "incoherent" X-ray scattering experiments (figure 4). Since the speckles reflect the exact real-space arrangement of the scattering volume, even subtle structural changes can alter the speckle pattern dramatically due to interference effects.

The combination of ultrafast pulses, huge peak intensity and a high degree of beam coherence is truly unique to FEL facilities and has already enabled experiments that otherwise were impossible. In addition, the European XFEL has a huge average intensity due to the many pulses delivered each second. This allows a larger number of experimental sessions per operation cycle and/or better signal-to-noise ratios within a given experimental time frame. The destructive power of the beam means that many experiments will be of the single-shot type, which requires a continuous injection scheme because the sample cannot be reused. Other experiments will operate with reduced peak flux, allowing multi-exposure schemes as also demonstrated in work at LCLS and FLASH.

Six experimental stations are planned for the European XFEL start-up, two per SASE beamline. The first, situated at the hard-X-ray undulator SASE-1, is devoted to the study of single-particles and biomolecules, serial femtosecond crystallography, and femtosecond X-ray experiments in biology and chemistry. SASE-2 caters to dynamics investigations in condensed-matter physics and material-science experiments, specialising in extreme states of matter and plasmas. At the soft-X-ray branch SASE-3, two instruments will allow investigations of electronic states of matter and atomic/cluster physics, among other studies. The three SASE undulators will deliver photons in parallel and the instruments will share their respective beams in 12 hour shifts, so that three instruments are always operating at any given time.

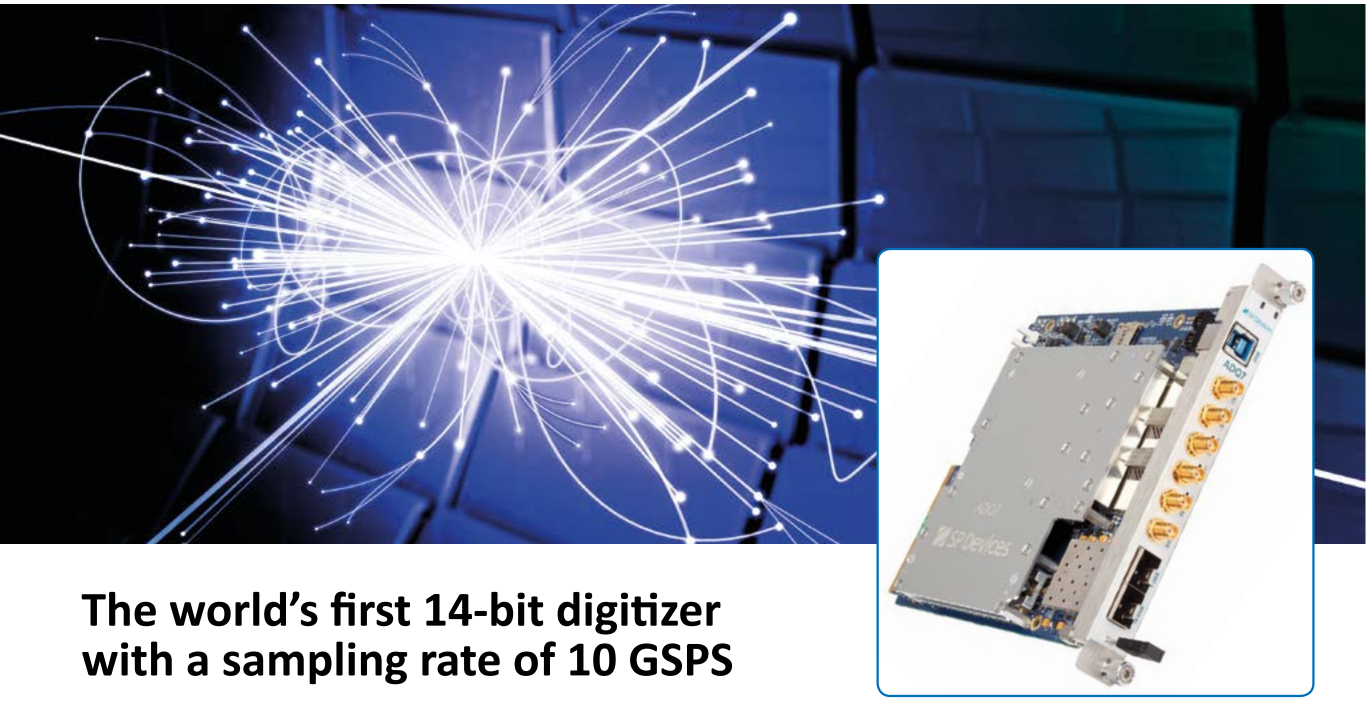
Eight years after the project officially began, the European XFEL finally achieved first light in 2017 and its commissioning is progressing according to schedule. The facility is the culmination of a worldwide effort lead by DESY concerning the electron linac and by European XFEL Gmbh for the development of X-ray photon transport and experimental stations. The facility is conveniently situated among other European light sources – synchrotrons that are also continuously evolving towards larger brilliance – and a handful of hard-X-ray FELs worldwide. The European XFEL is by far the most powerful hard-X-ray source in the world and will remain at the forefront for at least the next 20–30 years. Continuous investment in instrumentation and detectors will be required to capitalise fully on the impressive specifications, and the facility has the potential to construct about six additional instruments and possibly even a second experimental hall, all fed by X-rays generated by the existing superconducting electron linac. Without a doubt, Europe has now entered the extreme X-ray era.

Résumé

L'Europe dans une nouvelle ère des rayons X

XFEL, le laser à électrons libres à rayons X européen, sera tout prochainement disponible pour les premières expériences. Il fournira à ses utilisateurs, des scientifiques issus de diverses disciplines, des rayons X intenses atteignant jusqu'à 27 000 pulsations par seconde, qui permettront d'obtenir des images de processus électroniques, chimiques et biologiques avec un niveau de détail sans précédent. L'installation, située en Allemagne, est l'accomplissement d'un effort mondial, et elle représente une grande avancée dans la science des rayons X : elle promet les faisceaux les plus brillants, les énergies les plus hautes pour des photons et les cadences de répétition les plus élevées. La construction de cette installation, d'un coût de 1,2 milliard d'euros, a commencé en janvier 2009 grâce au financement de 11 pays, l'Allemagne et la Russie étant les principaux contributeurs.

Anders Madsen and **Harald Sinn**, European XFEL GmbH, Germany.



The world's longest superconducting linac

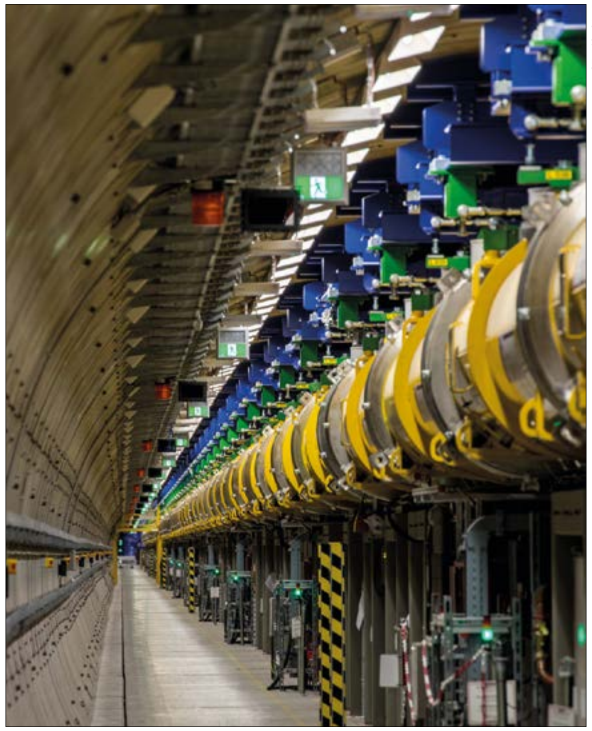
Underpinning the European XFEL is the longest superconducting linear accelerator ever built, involving international collaboration and advanced RF technology initially developed for a linear collider.

The European X-ray Free Electron Laser (European XFEL) now entering operations at Hamburg in Germany will generate ultra-short X-ray flashes at a rate of 27,000 per second with a peak brilliance one billion times higher than the best conventional X-ray sources. The outstanding characteristics of the facility will open up completely new research opportunities for scientists and industrial users (see p18). Involving close co-operation with nearby DESY and other organisations worldwide, the European XFEL is a joint effort between many countries. No fewer than 17 European institutes contributed to the accelerator complex, with the largest in-kind (> 70%) and other contributions coming from DESY.

The story of the European XFEL is a wonderful example of R&D synergy between the high-energy physics and light-source worlds. At the heart of the European XFEL are superconducting radio-frequency (SRF) cavities that allow the 1.4 km-long linac to accelerate electrons highly efficiently. Despite the clear benefits of using SRF cavities, before the mid-1990s the technology was not mature enough and too expensive to be practical for a large facility. Experience gained at DESY and other major accelerator facilities – including LEP at CERN and CEBAF at Jefferson Lab – changed that picture. It became clear that superconducting accelerating structures with reasonably large gradients can produce high-energy electron beams in long continuous linac sections.

Enter TESLA

A major character in the European XFEL story is the TESLA (TeV Energy Superconducting Linear Accelerator) collaboration, which was founded in 1990 by key players of the SRF community. Among its challenges was to make SRF cavities more affordable. DESY offered to host essential infrastructure and a test facility to operate newly designed accelerator modules housing eight standardised cavities. The first module was built in the mid-1990s in collaboration with many of the later contributors to the European XFEL, and the first electron beam was accelerated in 1997.



D Nölle/DESY

The main linac, suspended from the ceiling to leave space at floor level, photographed in January 2017.

The enormous flexibility in how electron bunches can be structured has meant that there has long been a close connection between free-electron lasers and superconducting accelerator technology from the beginning: examples can be found at Stanford University, Darmstadt University and Dresden Rossendorf, Jefferson Lab, and DESY. From the start of the TESLA R&D, it was envisaged that SRF technology would drive a superconducting linear collider operating at a centre-of-mass energy of 500 GeV, with the possibility of extending this to 800 GeV. This facility would have had two linear accelerators pointing towards one another: one for electrons, which would also be used to drive an X-ray laser facility, and one for positrons. At the time, high-energy physicists were weighing up other linear-collider designs in the US and Japan, but TESLA was unique in its choice of superconducting accelerating ▷

cavities. In 1997, DESY and the TESLA collaboration published a Conceptual Design Report for a superconducting linear collider with an integrated X-ray laser facility.

Although DESY was preparing for a hard-X-ray FEL, first the goal was to build an intermediate facility operating at slightly lower X-ray energies (corresponding to an output in the VUV region). In 2005 the VUV-FEL at DESY (today known as FLASH) produced laser light at a wavelength of 30 nm based on the principle of self-amplified-spontaneous-emission (SASE), which allows the generation of coherent X-ray light. The project preparation phase for the European XFEL began in 2007, with the official start declared in 2009 after the foundation of the European XFEL company. Plans to build a linear collider at DESY were dropped, but in 2004 the TESLA design was chosen for a new International Linear Collider (ILC). This machine is now "shovel ready" and the Japanese government has expressed interest in hosting it, although a final decision is awaited. Since the European XFEL uses TESLA technology at a large scale, the now finished superconducting linac can be considered as a prototype for the linear collider. Moreover, the successful technology transfer with industry that underpinned the construction of the European XFEL serves as a model for a worldwide linear collider effort.

The European XFEL, measuring 3.4 km in length, begins with the injector, which comprises a normal-conducting RF electron gun with a high bunch charge and low emittance. This is followed by a standard superconducting eight-cavity XFEL accelerator module, which takes the electron bunch to an energy of around 130 MeV. A harmonic 3.9 GHz accelerator module (provided by INFN and DESY) further alters the longitudinal beam profile, while a laser heater provided by Uppsala University increases the uncorrelated energy spread. At the end of the injector, 600 µs-long electron-bunch trains of typically 500 pC bunches are available for acceleration.

Once in the main linac of the European XFEL, the electron beam is accelerated in three sections. The first consists of four superconducting XFEL modules and presents a fairly modest gradient (far below the XFEL design gradient of 23.6 MV/m). The second linac section consists of 12 accelerator modules, from which the beam emerges with a relative energy spread of 0.3% at 2.4 GeV. The third and last linac section consists of 80 accelerator modules with an installed length of just less than 1 km. Bunch-compressor sections between the three main linac sections include dipole-magnet chicanes, further focusing elements and beam diagnostics.

Taking into account all installed main-linac accelerator modules, the achievable electron beam energy of the European XFEL is above its design energy of 17.5 GeV, although the exact figure will depend on optimising the RF control. The complete linac is suspended from the ceiling to keep the tunnel floor free for transport and the installation of electronics. During accelerator operation the electrons are distributed via fast kicker magnets into one of the two electron beamlines that feed several photon beamlines. Here, undulators provide X-ray photon beams for various experiments (see p18).

A sophisticated supply chain was established.

D Nölle/DESY

A superconducting cavity resonator for the European XFEL linac, measuring around 1 m long and pictured in a test configuration.

Meeting the production challenge

The superconducting accelerator modules for the European XFEL linac were contributed by DESY, CEA Saclay and LAL Orsay in France, INFN Milano in Italy, IPJ Swierk and Soltan Institute in Poland, CIEMAT in Spain and BINP in Russia. More than 100 modules were needed, and although they were based on a prototype developed for the TESLA linear collider, they had to be modified for large-scale industrial production. DESY, which had responsibility for the construction and operation of the particle accelerator, developed a consortium scheme in which collaborators could contribute in-kind, either by producing sub-components or by assuming responsibility for module assembly or component testing. A sophisticated supply chain was established and the pioneering work at FLASH provided invaluable help in dealing with initial challenges.

A standard accelerator module contains eight superconducting cavities, each supplied by one RF power coupler, and a superconducting quadrupole package, which includes correction coils and a beam-position monitor. Each module also contains cold vacuum components such as bellows and valves, and frequency tuners. During the R&D and project preparation phases, less than one accelerator module per year was assembled, thus it took a factor 30 increase in production rate to build the European XFEL. Two European companies – Research Instruments in Germany and Zanon in Italy – shared the task of producing 800 superconducting cavities from solid niobium. Cavity string and module assembly took place at CEA Saclay/Irfu based on

R Frommann

D Nölle/DESY

(Top) Connecting modules in the European XFEL linear accelerator. (Above) Superconducting accelerator modules in a test facility at DESY in October 2014.

completely new infrastructure called the XFEL village. Assembly was directly impacted by the availability of all accelerator module sub-components, and any break in the supply chain was seen as a risk for the overall project schedule. In the end, a total of 96 successfully tested XFEL modules were made available for tunnel installation within a period of just two years.

The operation of the superconducting accelerator modules also requires extensive dedicated infrastructure. DESY provided the RF high-power system and developed the required 10 MW multi-beam klystrons with industrial partners. A total of 27 klystrons, each supplying RF power for 32 superconducting structures (four accelerator modules), were ordered from two vendors. Precision regulation of the RF fields inside the accelerating cavities, which is essential to provide a highly reproducible and stable electron beam, is achieved by a powerful control system developed at DESY. BINP Novosibirsk produced and delivered major cryogenic equipment for the linac, while the cryogenic plant itself (an in-kind contribution from DESY) guarantees pressure variations will stay below 1%. The largest visible contributions to the warm beamline sections are the more than 700 beam-transport magnets and the 3 km vacuum system in the different sections. While most of the magnets were delivered by the Efremov Institute in St Petersburg, a small fraction was built by BINP Novosibirsk and completed at Stockholm University. Many metres of beamline, be it simple straight chambers or the more sophisticated flat bunch-compressor chambers, were also fabricated by BINP Novosibirsk.

State-of-the-art electron-beam diagnostics is vital for the success of the European XFEL. Thus 64 screens and 12 wire scanner stations, 460 beam-position monitors of eight different types, 36 toroids and six dark-current monitors are distributed along the accelerator. Longitudinal bunch properties are measured by bunch-compression monitors, beam-arrival monitors, electro-optical devices and transverse deflecting systems. Major contributions to the electron-beam diagnostics came from DESY, PSI in Switzerland, CEA Saclay in France, and from INR Moscow in Russia.

Technology goes full circle

Commissioning for the European XFEL accelerator began in December 2016 with the cool-down of the complete cryogenic system. First beam was injected into the main linac in January 2017, and by March bunches with a sufficient beam quality to allow lasing were accelerated to 12 GeV and stopped in a beam dump. After passing this beam through the "SASE1" undulator, first lasing at a wavelength of 0.9 nm was observed on 2 May. Further improvements to the beam quality and alignment led to lasing at 0.2 nm on 24 May. More than 90% of the installed accelerator modules are now in RF operation, with effective accelerating gradients reaching the expected performance in fully commissioned stations.

The first hard-X-ray SASE free-electron laser, the Linac Coherent Light Source (LCLS) at SLAC in the US, was based on a normal-conducting accelerator. Upgrades to LCLS-II now aim for continuous wave operation using 280 superconducting cavities of essentially the same design as those of the European XFEL. Improvements to the superconducting technology were made to further reduce the cryogenic load of the accelerator structures. New techniques such as nitrogen doping and infusion, developed by Fermilab and other LCLS-II partners, are also essential, and established procedures and expertise with series production will benefit future FEL user operation. The now existing European SRF expertise and collaboration scheme also sketches out a mechanism for a European in-kind contribution to a Japan-hosted ILC.

The European XFEL is one of the largest accelerator-based research facilities in the world, and is driven by the longest and most advanced superconducting linac ever constructed. This was possible thanks to the great collaborative effort and team spirit of all partners involved in this project over the past 20 years or more.

Résumé

Construction du linac supraconducteur le plus long du monde

L'installation européenne XFEL peut compter sur l'accélérateur linéaire supraconducteur le plus long jamais construit, qui mesure 2 km de long. Ce dernier utilise des cavités radiofréquence supraconductrices perfectionnées pour accélérer des électrons à une énergie de 17,5 GeV, qu'il dirige ensuite vers des ondulateurs afin de produire des pulsations intenses de rayons X de type laser, destinées aux expériences. Cette technologie, développée à DESY, fait également office de prototype pour un possible collisionneur linéaire de haute énergie destiné à la physique des particules.

Hans Weise and **Winfried Decking**, DESY.

Discovering diamonds

A new technique for sorting diamond from rock based on technology developed for high-energy physics detectors is poised to make mines more efficient.

Natural diamonds are old, almost as old as the planet itself. They mostly originated in the Earth's mantle around 1 to 3.5 billion years ago and typically were brought to the surface during deep and violent volcanic eruptions some tens of millions of years ago. Diamonds have been sought after for millennia and still hold status. They are also one of our best windows into our planet's dynamics and can, in what is essentially a galactic narrative, convey a rich story of planetary science. Each diamond is unique in its chemical and crystallographic detail, with micro-inclusions and impurities within them having been protected over vast timescales.

Diamonds are usually found in or near the volcanic pipe that brought them to the surface. It was at one of these, in 1871 near Kimberley, South Africa, where the diamond rush first began – and where the mineral that hosts most diamonds got its name: kimberlite. Many diamond sources have since been discovered and there are now more than 6000 known kimberlite pipes (figure 1 overleaf). However, with current mining extraction technology, which generally involves breaking up raw kimberlite to see what's inside, diamonds are often damaged and are steadily becoming mined out. Today, a diamond mine typically lasts for a few decades, and it costs around \$10–26 to process each tonne of rock. With the number of new, economically viable diamond sources declining – combined with high rates of diamonds being extracted, ageing mines and increasing costs – most forecasts predict a decline in rough diamond production compared to demand, starting as soon as 2020.

A new diamond-discovery technology called MinPET (mineral positron emission tomography) could help to ensure that precious sources of natural diamonds last for much longer. Inspired by the same principles adapted in modern, high-rate, high-granularity detectors commonly found in high-energy physics experiments, MinPET uses a high-energy photon beam and PET imaging to scan mined kimberlite for large diamonds, before the rocks are smashed to pieces.

From eagle eyes to camera vision

Over millennia, humans have invented numerous ways to look for diamonds. Early techniques to recover loose diamonds used the principle that diamonds are hydrophobic, so resist water but stick readily to grease or fat. Some stories even tell of eagles recovering diamonds from deep, inaccessible valleys, when fatty meat thrown onto a valley floor might stick to a gem: a bird would fly down, devour the meat, and return to its nest, where the diamond could be recovered from its droppings. Today, technology hasn't evolved much. Grease tables are still used to sort diamond from rock, and the current most popular technique for recovering diamonds (a process called dense media separation) relies on the principle that kimberlite particles float in a special slurry while diamonds sink. The excessive processing required with these ▷

older technologies wastes water, takes up huge amounts of land, releases dust into the surrounding atmosphere, and also leads to severe diamond breakage.

Just 1% of the world's diamond sources have economically viable grades of diamond and are worth mining. At most sites the gemstones are hidden within the kimberlite, so diamond-recovery techniques must first crush each rock into gravel. The more barren rock there is compared to diamonds, the more sorting has to be done. This varies from mine to mine, but typically is under one carat per tonne – more dilute than gold ores. Global production was around 127 million carats in 2015, meaning that mines are wasting millions of dollars crushing and processing about 100 million tonnes of kimberlite per year that contains no diamonds. We therefore have an extreme case of a very high value particle within a large amount of worthless material – making it an excellent candidate for sensor-based sorting.

Early forms of sensor-based sorting, which have only been in use since 2010, use a technique called X-ray stimulated optical fluorescence, which essentially targets the micro impurities and imperfections in each diamond (figure 2). Using this method, the mined rocks are dropped during the extraction process at the plant, and the curtain of falling rock is illuminated by X-rays, allowing a proportion of liberated or exposed diamonds to fluoresce and then be automatically extracted. The transparency of diamond makes this approach quite effective. When Petra Diamonds Ltd introduced this technique with several X-ray sorting machines costing around $6 million, the apparatus paid for itself in just a few months when the firm recovered four large diamonds worth around $43 million. These diamonds, presumed to be fragments of a larger single one, were 508, 168, 58 and 53 carats, in comparison to the average one-carat engagement ring.

Very pure diamonds that do not fluoresce, and gems completely surrounded by rock, can remain hidden to these sensors. As such, a newer sensor-based sorting technique that uses an enhanced form of dual-energy X-ray transmission (XRT), similar to the technology for screening baggage in airports, has been invented to get around this problem. It can recover liberated diamonds down to 5 mm diameter, where 1 mm is usually the smallest size recovered commercially, and, unlike the fluorescing technique, can detect some locked diamonds. These two techniques have brought the benefits of sensor-based sorting into sharp focus for more efficient, greener mines and for reducing breakage.

Recent innovations in particle-accelerator and particle-detector technology, in conjunction with high-throughput electronics, image-processing algorithms and high-performance computing, have greatly enhanced the economic viability of a new diamond-sensing technology using PET imaging. PET, which has strongly benefitted from many innovations in detector development at CERN, such as BGO scintillating crystals for the LEP experiments, has traditionally been used to observe processes inside the body. A patient must first absorb a small amount of a positron-emitting isotope; the ensuing annihilations produce patterns of gamma rays that can be reconstructed to build a 3D picture of metabolic activity. Since a rock cannot be injected with such a tracer, MinPET requires us to irradiate rocks with a high-energy photon beam and generate the positron emitter via transmutation.

Fig. 1. A mine near Mirny, Russia, where a kimberlite pipe meets the surface.

Eric Welch/GIA

Fig. 2. Diamonds fluoresce in different ways under excitation, which is the principle by which X-ray fluorescence works.

The birth of MinPET

The idea to apply PET imaging to mining began in 1988, in Johannesburg, South Africa, where our small research group of physicists used PET emitters and positron spectroscopy to study the crystal lattice of diamonds. We learnt of the need for intelligent sensor-based sorting from colleagues in the diamond mining industry and naturally began discussing how to create an integrated positron-emitting source.

Advances in PET imaging over the next two decades led to increased interest from industry, and in 2007 MinPET achieved its first major success in an experiment at Karolinska hospital in Stockholm, Sweden. With a kimberlite rock playing the role of a patient, irradiation was performed at the hospital's photon-based cancer therapy facility and the kimberlite was then imaged at the small-animal PET facility in the same hospital. The images clearly revealed the diamond within, with PET imaging of diamond in kimberlite reaching an activity contrast of more than 50 (figure 3). This result led to a working technology demonstrator involving a conveyor belt that presented phantoms (rocks doped with a sodium PET-emitter were used to represent the kimberlite, some of which contained a sodium hotspot to represent a hidden diamond) to a PET camera. These promising results attracted funding, staff and students, enabling the team to develop a MinPET research laboratory at iThemba LABS in Johannesburg. The work also provided an

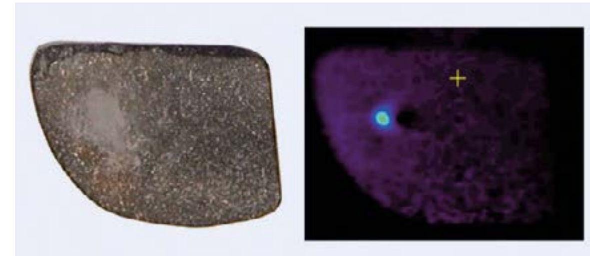


Fig. 3. PET image (right) of a 5 cm-wide kimberlite rock spiked with a diamond.

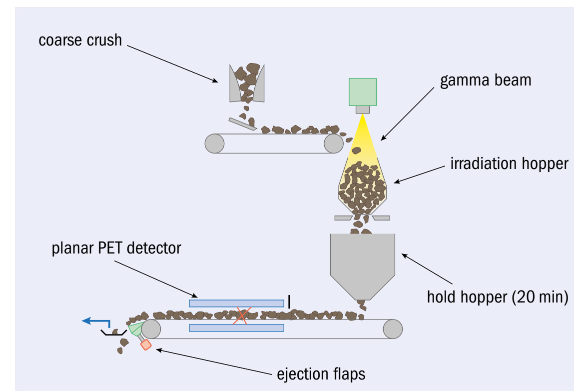


Fig. 4. MinPET activates the material with gamma rays before sending the material along a conveyor belt between two planar PET detector arrays to be sorted.

All image credits on this page: S Connell

The MinPET technology demonstrator with an early version of the detector system, showing kimberlite rock on a conveyor belt (top) and a recent Mark II MinPET camera system (above).

important early contribution to South Africa's involvement in the ATLAS experiment at CERN's Large Hadron Collider.

By 2015 the technology was ready to move out of the lab and into a diamond mine. The MinPET process (figure 4) involves using a high-energy photon beam of some tens of MeV to irradiate a kimberlite rock stream, turning some of the light stable isotopes within the kimberlite into transient positron emitters, or PET isotopes, which can be imaged in a similar way to PET imaging for medical diagnostics. The rock stream is buffered for a period of 20 minutes before imaging the rock, because by then carbon is the dominant PET isotope. Since non-diamond sources of carbon have a much lower carbon concentration than diamond, or are diluted and finely dispersed within the kimberlite, diamonds show up on the image as a carbon-concentration hotspot.

The speed of imaging is crucial to the viability of MinPET. The detector system must process up to 1000 tonnes of rock per hour to meet the rate of commercial rock processing, with PET images acquired in just two seconds and image processing taking just five seconds. This is far in excess of medical-imaging needs and required the development of a very high-rate PET camera, which was optimised, designed and manufactured in a joint collaboration between the present authors and a nuclear electronic technology start-up called NeT Instruments. MinPET must also take into account rate capacity, granularity, power consumption, thermal footprints and improvements in photon detectors. The technology demonstrator is therefore still used to continually improve MinPET's performance, from the camera to raw data event building and fast-imaging algorithms.

An important consideration when dealing with PET technology is that radiation remains within safe limits. If diamonds are exposed to extremely high doses of radiation, their colour can change – something that can be done deliberately to alter the gems, but which reduces customer confidence in a gem's history. Despite being irradiated, the dose exposure to the diamonds during the MinPET activation process is well below the level it would receive from nature's own background. It has turned out, quite amazingly, that MinPET offers a uniquely radiologically clean scenario. The carbon PET activity and a small amount of sodium activity are the only significant activations, and these have relatively short half-lives of 20 minutes and 15 hours, respectively. The irradiated kimberlite stream soon becomes indistinguishable from non-irradiated kimberlite, and therefore has a low activity and allows normal mine operation.

Currently, XRT imaging techniques require each particle of kimberlite rock being processed to be isolated and smaller than 75 mm; within this stream only liberated diamonds that are at least 5 mm wide can be detected and XRT can only provide 2D images. MinPET is far more efficient because it is currently able to image locked diamonds with a width of 4 mm within a 100 mm particle ▷

Mineral PET

of rock, with full 3D imaging. The size of diamonds MinPET detects means it is currently ideally suited for mines that make their revenue predominantly from large diamonds (in some mines breakage is thought to cause up to a 50% drop in revenue). There is no upper limit for finding a liberated diamond particle using MinPET, and it is expected that larger diamonds could be detected in up to 160 mm-diameter kimberlite particles.

To crumble or shine

MinPET has now evolved from a small-scale university experiment to a novel commercial technology, and negotiations with a major financial partner are currently at an advanced stage. Discussions are also under way with several accelerator manufacturers to produce a 40 MeV beam of electrons with a power of 40–200 kW, which is needed to produce the original photon beam that kick-starts the MinPET detection system.

Although the MinPET detection system costs slightly more than other sorting techniques, overall expenditure is less because processing costs are reduced. Envisaged MinPET improvements over the next year are expected to take the lower limit of discovery down to as little as 1.5 mm for locked diamonds. The ability to reveal entire diamonds in 3D, and locating them before the rocks are crushed, means that MinPET also eliminates much of the breakage and damage that occurs to large diamonds. The technique also requires less plant, energy and water – all without causing any impact on normal mine activity.

The world's diamond mines are increasingly required to be greener and more efficient. But the industry is also under pressure to become safer, and the ethics of mining operations are a growing concern among consumers. In a world increasingly favouring transparency and disclosure, the future of diamond mining has to be in using intelligent, sensor-based sorting that can separate diamonds from rock. MinPET is the obvious solution – eventually allowing marginal mines to become profitable and the lifetime of existing mines to be extended. And although today's synthetic diamonds offer serious competition, natural stones are unique, billions of years old, and came to the surface in a violent fiery eruption as part of a galactic narrative. They will always hold their romantic appeal, and so will always be sought after.

Résumé

Sur les traces des diamants

Des physiciens des particules ont développé, à partir d'une technologie créée pour des détecteurs de physique des hautes énergies, une nouvelle technique pour distinguer les diamants de la roche. Celle-ci, appelée MinPET, utilise la tomographie par émission de positons pour créer des images 3D de la roche et mettre en évidence les diamants qu'elle contient en détectant la fluorescence. Issue d'une expérience à petite échelle au sein d'une université, cette technique est devenue une technologie commerciale novatrice, qui apporte la promesse de mines de diamants plus productives et plus respectueuses de l'environnement.

Simon Connell, **Martin Cook** and **Sergio Ballestrero**, University of Johannesburg, South Africa.

The Higgs adventure: five years in

Five years since the ATLAS and CMS collaborations discovered the Higgs boson, much has been learnt about this most fascinating scalar object. But we are still only at the beginning of our journey of understanding.

Where were you on 4 July 2012, the day the Higgs boson discovery was announced? Many people will be able to answer without referring to their diary. Perhaps you were among the few who had managed to secure a seat in CERN's main auditorium, or who joined colleagues in universities and laboratories around the world to watch the webcast. For me, the memory is indelible: 3.00 a.m. in Watertown, Massachusetts, huddled over my laptop at the kitchen table. It was well worth the tired eyes to witness remotely an event that will happen once in a lifetime.

"I think we have it, no?" was the question posed in the CERN auditorium on 4 July 2012 by Rolf Heuer, CERN's Director-General at the time. The answer was as obvious as the emotion on faces in the crowd. The then ATLAS and CMS spokespersons, Fabiola Gianotti and Joe Incandela, had just presented the latest Higgs search results based on roughly two years of LHC operations at energies of 7 and 8 TeV. Given the hints for the Higgs presented a few months earlier in December 2011, the frenzy of rumours on blogs and intense media interest during the preceding weeks, and a title for the CERN seminar that left little to the imagination, the outcome was anticipated. This did not temper excitement.

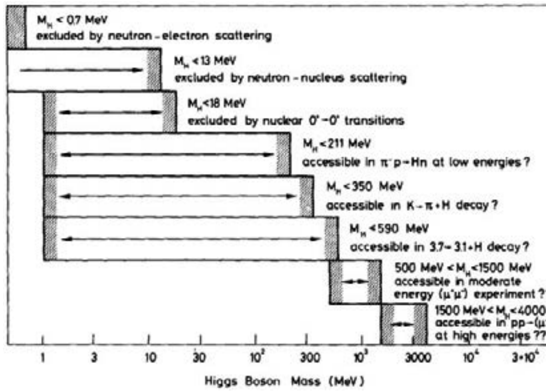
Since then, we have learnt much about the properties of this new scalar particle, yet we are still at the beginning of our understanding. It is the final and most interesting particle of the Standard Model of particle physics (SM), and its connections to many of the deepest current mysteries in physics mean the Higgs will remain a focus of activities for experimentalists and theorists for the foreseeable future.

Speculative theories

The Higgs story began in the 1960s with speculative ideas. Theoretical physicists understood how the symmetries of materials can spontaneously break down, such as the spontaneous alignment of atoms when a magnet is cooled from high temperatures, but it was not yet understood how this might happen for the symmetries present in the fundamental laws of physics. Then, in three separate publications by Brout and Englert, by Higgs, and by Guralnik, Hagen and Kibble in 1964, the broad particle-physics structures for spontaneous symmetry breaking were fleshed out. In this and subsequent work it became clear that a scalar field was a cornerstone of the general symmetry-breaking mechanism. This field may be excited and oscillate, much like the ripples that appear on a disturbed pond, and the excitation of the Higgs field is known as the Higgs boson.

As the detailed theoretical structure of symmetry breaking in nature was later developed, in particular by Weinberg, Glashow, Salam, 't Hooft and Veltman, the precise role of the Higgs in the SM evolved to its modern form. In addition to explaining what we see in modern particle detectors, the Higgs plays a leading role in the evolution of the universe. In the hot early epoch an infinitesimally small fraction of a second after the Big Bang, the Higgs field spontaneously "slipped" from having zero average value everywhere in space to having an average value equivalent to about 246 GeV. When this happened, any field that was previously kept massless by the $SU(2) \times U(1)$ gauge symmetries of the SM instantly became massive.

Before delving further into the vital role of the Higgs, it is worth revisiting a couple of common misconceptions. One is that the Higgs boson gives mass to all particles. Although all of the *known* massive fundamental particles obtain their mass by interacting with the pervasive Higgs field, there are non-elementary particles, such as the proton, whose mass is dominated by the binding energy of the strong force that holds its constituent gluons and quarks together. So very little of the mass we see in nature comes directly from the Higgs field. Another misconception is that the Higgs boson gives mass to everything it interacts with. On the contrary, the Higgs has very important interactions with two massless fundamental fields: the photon and the gluon. The Higgs is not charged under the forces associated with the photon and the gluon (quantum electrodynamics and quantum chromodynamics), and therefore cannot give them mass, but it can still interact with them. Indeed, somewhat ironically, it was precisely its interactions with massless gluons and photons that revealed the existence of the Higgs boson in the summer of 2012.



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(Top) In Search of the Higgs Boson, *a series of works produced by artist Xavier Cortada and physicist Pete Markowitz. (Image credit: X Cortada.) Fig. 1. (Above) Possible Higgs boson mass and the relevant method for discovery, as considered in the landmark 1975 paper by Ellis, Gaillard and Nanopoulos.*

The one remaining unmeasured free parameter of the SM at that time, which governs which production and decay modes the particle can have, was the Higgs boson mass. In the early days it was not at all clear what the mass of the Higgs boson would be, since in ▷

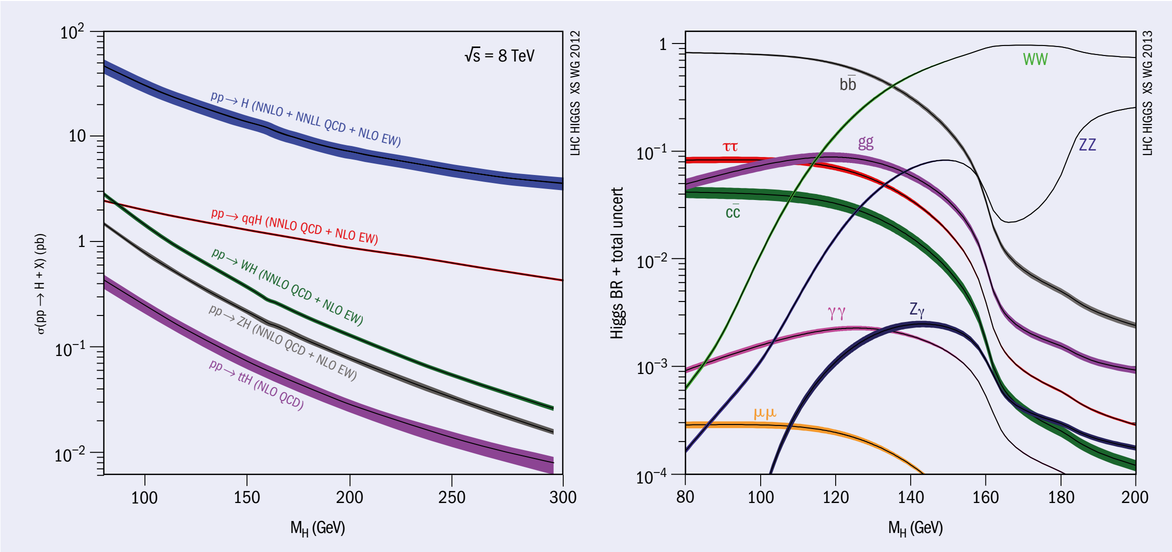


Fig. 2. Possibilities for the Higgs boson discovery at the LHC before 2012. (Left) Different Higgs cross-sections as a function of mass, with lower lines showing scenarios where a Higgs boson is produced in association with another particle and the top line showing the single-Higgs production cross-section, which is dominated by gluon fusion. (Right) The relative rates for the Higgs boson to decay into different particles for different Higgs boson mass values. Lighter Higgs bosons can observably decay to a variety of final states.

the SM this is an input parameter of the theory. Indeed, in 1975, in the seminal paper about its experimental phenomenology by Ellis, Gaillard and Nanopoulos, it is notable that the allowed Higgs mass range at that time spanned four orders of magnitude, from 18 MeV to over 100 GeV, with experimental prospects in the latter energy range opaque at best (figure 1, previous page).

How the Higgs was found

By 4 July 2012 the picture was radically different. The Higgs no-show at previous colliders, including LEP at CERN and the Tevatron at Fermilab, had cornered its mass to be greater than 114 GeV and not to lie between 147–180 GeV, while theoretical limits on the allowed properties of W- and Z-boson scattering required it to be below around 800 GeV. If nature used the SM version of the Higgs mechanism, there was nowhere left to hide once CERN's LHC switched on. In the end, the Higgs weighed in at the relatively light mass of 125 GeV. How the different Higgs cross-sections, which are related to the production rate for various processes, depend on the mass are shown in figure 2, left.

Producing the Higgs would alone not be sufficient for discovery. It would also have to be observed, which depends on the different fractional ways in which the Higgs boson will decay (figure 2, right). If heavy, one would have to search for decays to the weak gauge bosons, W and Z; if lighter, a cocktail of decays would light up detectors. Going further, if thousands of Higgs bosons could be produced, then decays to pairs of photons may show up. Thus, by the time of the LHC operation, the basic theoretical recipe was relatively simple: pick a Higgs mass, calculate the SM predictions and search.

On the other hand, the experimental recipe was far from simple. The LHC, a particle accelerator capable of colliding protons at energies far beyond anything previously achieved, was a necessity. But energy alone was not enough, as sufficient numbers of Higgs bosons also had to be produced. Although occurring at a low rate, Higgs decays into pairs of massless photons would prove to be experimentally clean and furnish the best opportunity for discovery. Once detection efficiencies, backgrounds, and requirements of statistical significance are folded into the mix, on the order of 100,000 Higgs bosons would be required for discovery. This is no short order, yet that is what the accelerator teams delivered to the detectors.

With the accelerator running, it remained to observe the thing. This would push ingenuity to its limits. Physicists on the ATLAS and CMS detectors would need to work night and day to filter through the particle detritus from innumerable proton–proton collisions to select data sets of interest. The search set tremendous challenges for the energy-resolution and particle-identification capabilities of the detectors, not to mention dealing with enormous volumes of data. In the end, the result of this labour reduced to a couple of plots (figure 3). The discovery was clear for each collaboration: a significance pushing the 5σ "discovery" threshold. In further irony for the mass-giving Higgs, the discovery was driven primarily by the rare but powerful diphoton decays, followed closely by Higgs decays to Z bosons. Global media erupted in a science-fuelled frenzy. It turns out that everyone gets excited when a fundamental building block of nature is discovered.

The hard work begins

The joy in the experimental and theoretical communities in the summer of 2012 was palpable. If we were to liken early studies of the electroweak forces to listening to a crackling radio, LEP had given us black and white TV and the LHC was about to show us

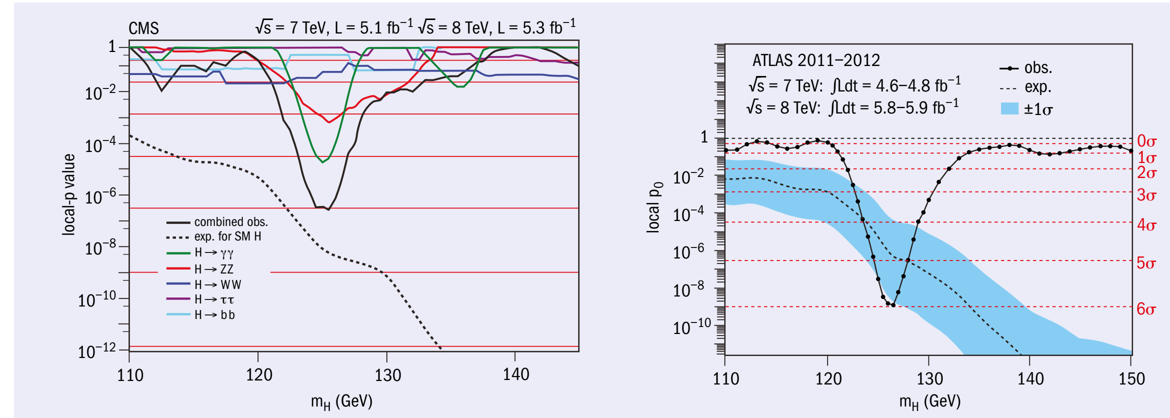


Fig. 3. The discovery of the Higgs boson at ATLAS and CMS, as reported in two papers (arXiv:1207.7214 and arXiv:1207.7235) published after the 4 July announcement. Black lines show the local "p-value", which is the probability that the observation is a statistical fluctuation and not the Higgs boson. This p-value is less than one part in a million, similar to the probability of flipping a coin 21 times and it coming up heads on every occasion, and the significance is peaked at the same mass for both experiments.

the world in full cinematic colour. Particle physicists now had the work they had waited a lifetime to do. Is it the SM Higgs boson, or something else, something exotic? All we knew at the time was that there was a new boson, with mass of roughly 125 GeV, that decayed to photons and Z bosons.

Despite the huge success of the SM, there was every reason to hope that the new boson would not be of the common variety. The Higgs brings us face-to-face with questions that the SM cannot answer, such as what constitutes dark matter (observed to make up roughly 80% of all the matter in the universe). Unlike the other SM particles, it is uncharged and without spin, and can therefore interact easily with any other neutral scalar particles. This makes it a formidable tool in the hunt for dark matter – a possibility we often call the "Higgs portal". The ATLAS and CMS collaborations have been busy exploring the Higgs portal and we now know that the Higgs decay rate into invisible new dark particles must be less than 34% of its total rate into known particles. This is an incredible thing to know for a particle that is itself so elusive, and a significant early step for dark-sector physics.

Another deep puzzle, even more esoteric than dark matter and which has driven the theoretical community to distraction for decades, is called the hierarchy problem. We know that at higher energies (smaller sizes) there must be more structure to the laws of nature: the scale of quantum gravity, the Planck scale, is one example, but there are hints of others. For any other SM particle, this new physics at high energies has no dramatic effect, since fundamental particles with nonzero spin possess special protective symmetries that shield them from large quantum corrections. But the Higgs possesses no such symmetry, and is thus a sensitive creature: quantum-mechanical effects will give large corrections to its mass, pulling it all the way up to the masses of the new particles it is interacting with. That has clearly not happened, given the mass we measure in experiments, so what is going on?

It turns out everyone gets excited when a fundamental building block of nature is discovered.

Thus the discovery of the Higgs brings the hierarchy problem to the fore. If the Higgs is composite, being made up of other particles, in a similar fashion to the ubiquitous QCD pion, then the problem simply goes away because there is no fundamental scalar in the first place. Another popular theory, supersymmetry, postulates new space–time symmetries, which protect the Higgs boson from these quantum corrections and could modify its properties. Measurements of the Higgs interactions thus indirectly probe this deepest of questions in modern particle physics. For example, we now know the interaction between the Higgs boson and the Z boson to an accuracy at the level of 10%, a significant constraint on these theories.

It is also crucial that we understand the way the Higgs interacts with fermions. Anyone who has ever looked up the masses of the quarks and leptons will see that they follow cryptic hierarchical patterns, while families of fermions can also mix into one another through the emission of a W boson in peculiar patterns that we do not yet understand. By playing a star role in generating particle masses, and as a supporting actor by also generating the mixings, the Higgs could shed light on these mysteries.

At the time of the Higgs discovery in 2012, the only interactions we were certain of concerned bosons: photons, W and Z bosons, and, to a certain degree, gluons. There was emerging evidence for interactions with top quarks, but it was circumstantial, coming from the role of the top quark in the quantum-mechanical process that generates Higgs interactions with gluons and photons. After a four-year wait, in 2016 ATLAS and CMS combined forces to reach the first 5σ direct discovery of Higgs interactions with a fermion: the τ lepton, to be precise. This was a significant milestone, not least because it also happened to give the first ▷

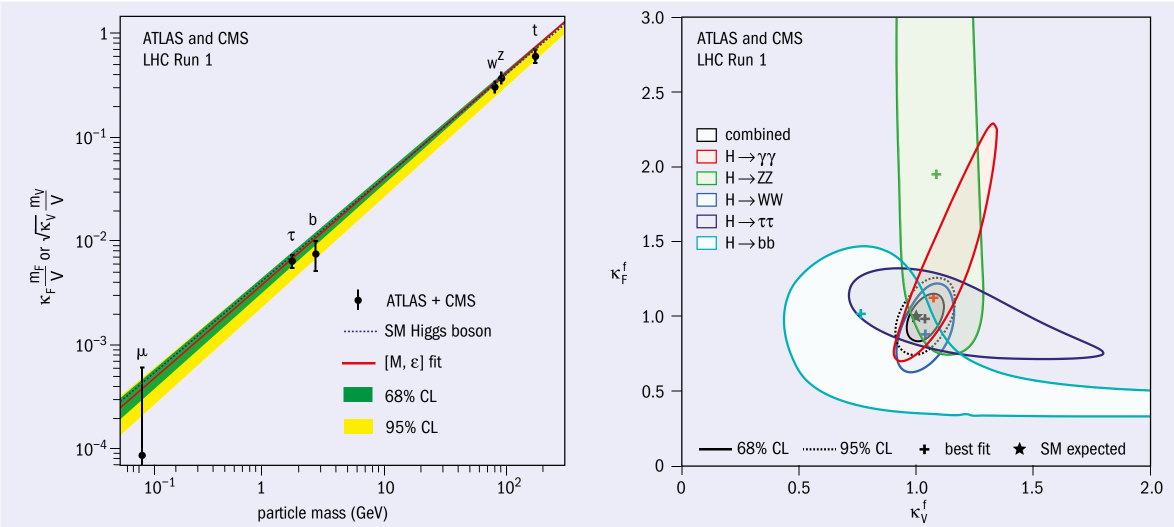


Fig. 4. (Left) The mass the Higgs boson bestows on other particles depends on its interaction strength with that particle. Knowing the mass of a particle we may therefore predict (dashed blue line) how strongly it interacts with the Higgs boson. LHC measurements are shown in black, corroborating the predictions of the SM over many orders of magnitude in interaction strength. (Right) The strength of the Higgs coupling to fermions versus vector bosons, as measured by ATLAS and CMS based on Run 1 data for individual decay channels (colours) and their global combination (grey).

direct evidence of Higgs interactions with leptons.

The scope of the Higgs programme has also broadened since the early days of the discovery. This applies not only to the precision with which certain couplings are measured, but also to the energy at which they are measured. For example, when the Higgs boson is produced via the fusion of two gluons at the LHC, additional gluons or quarks may be emitted at high energies. By observing such "associated production" we may gain information about the magnitude of a Higgs interaction and about its detailed structure. Hence, if new particles that influence Higgs boson interactions exist at high energies, probing Higgs couplings at high energies may reveal their existence. The price to be paid for associated production is that the probability, and hence the rate, is low (figure 2). As an ever increasing number of Higgs production events have been recorded at the LHC in the past five years, this has allowed physicists to begin mapping the nature of the Higgs boson's interactions.

What's next?

We have much to anticipate. Although the Higgs is too light to be able to decay into pairs of top quarks, experimentalists will study its interactions with the top quark by observing Higgs produced in association with pairs of top quarks. Another anticipated discovery, which is difficult to pick out above other background processes, is the decay of the Higgs to bottom quarks. Amazingly, despite the incredibly rare signal rate, the upgraded High-Luminosity LHC will be able to discover Higgs decays to muons. This would be the first observation of Higgs interactions with the second generation of fermions, pointing a floodlight towards the flavour puzzle. These measurements will bring the overall picture of how the Higgs generates particle masses into closer focus. Even now, after only five years, the picture is becoming clear: Higgs physics is becoming a precision science at the LHC (figure 4).

There is more to Higgs physics than a shopping list of couplings, however. By the end of the LHC's operation in the mid-2030s, more than one hundred million Higgs bosons will have been produced. That will allow us to search for extremely rare and exotic Higgs production and decay modes, perhaps revealing a first crack in the SM. On the opposing flank, by observing the standard production processes in extreme kinematic corners, such as Higgs production at very high momentum, we will be able to measure its interactions over a range of energies. In both cases the challenge will not only be experimental, as the SM predictions must also keep pace with the accuracy of the measurements – a fact which is already driving revolutions in our theoretical understanding (*CERN Courier* April 2017 p18).

Setting our sights on the distant future of Higgs physics, it would be remiss to overlook the "white whale" of Higgs physics: the Higgs self-interaction. In yet another unique twist, the Higgs is the only particle in the SM that can scatter off itself (figure 5). In contrast, gluons only interact with other non-identical gluons. If we could access the Higgs self-interactions, by determining how a Higgs boson scatters on itself in measurements of Higgs boson pair-production processes, we would be measuring the shape of the Higgs scalar potential. This is tremendously important because, in theory, it determines the fate of the entire universe: if the scalar potential "turns back over" again at high field values, it would imply that we live in a metastable state. There is mounting evidence, in the form of the measured SM parameters such as the mass of the top quark, that this may be the case. Unfortunately, with the LHC we will not be able to measure this

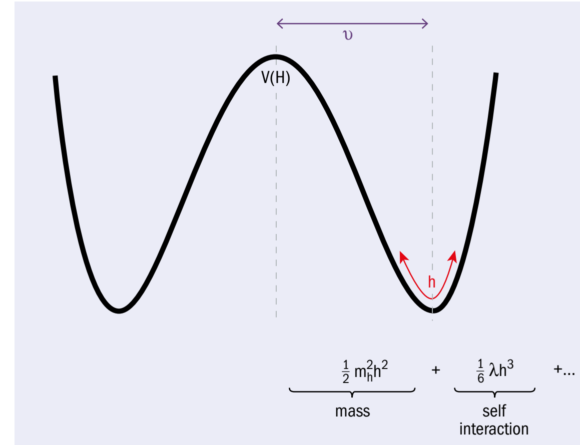


Fig. 5. The Higgs field sits at the bottom of its so-called "Mexican-hat" scalar potential. The second derivative of this potential is its mass, the third is its self-interaction, and so on to the fourth derivative, which allows four Higgs bosons to interact. Thus by measuring these interactions we would directly probe the shape of the scalar potential, and hence the dynamical mechanism by which the Higgs field spontaneously broke electroweak symmetry in the early universe.

interaction well enough to definitively determine the shape of the Higgs scalar potential, and so we must ultimately look to future colliders to answer this question, among others.

The Higgs is the keystone of the SM and therefore everything we learn about this new particle is central to the deepest laws of nature. When huddled over my laptop at 3.00 a.m. on 4 July 2012, I was 27 years old and in the first year of my first postdoctoral position. To me, and presumably the rest of my generation, it felt like a new scientific continent had been discovered, one that would take a lifetime to explore. On that day we finally knew it existed. Today, after five years of feverish exploration, we have in our hands a sketch of the coastline. We have much to learn before the mountains and valleys of the enigmatic Higgs boson are revealed.

Résumé

L'aventure du Higgs fête ses cinq ans

Cela fait cinq ans que les collaborations ATLAS et CMS ont annoncé la découverte du boson de Higgs au CERN. Depuis lors, la moisson de données du LHC nous en a appris beaucoup sur les propriétés de cette nouvelle particule scalaire, mais nous n'en sommes encore qu'au début. Particule finale et peut-être la plus intéressante du Modèle standard de la physique des particules, le boson de Higgs, qui est lié à certains des plus grands mystères actuels de la physique, restera ces prochaines années un important sujet d'étude pour les expérimentateurs comme pour les théoriciens. Il s'agit également d'un ingrédient crucial en ce qui concerne les arguments scientifiques pour un collisionneur post-LHC.

Matthew McCullough, CERN.

FAIR forges its future

Construction of the international FAIR complex in Germany began on 4 July, promising intense ion and antiproton beams for experiments in fields ranging from nuclear to atomic, plasma, biophysics and materials science.

Eighty foundation piles are currently being driven into the ground to create the retaining walls of the GSI facilities. (Image credit: G Otto/GSI.)

Supernova explosions, neutron-star mergers and rare radioactive ions might not seem to have much connection to terrestrial matters. Yet, while the lightest elements were synthesised immediately after the Big Bang, and elements up to iron were created in stellar cores, all of the heavy elements beyond gold and platinum were produced via complex production paths during extreme astrophysical events. Experiments with intense heavy-ion beams produced at the international Facility for Antiproton and Ion Research (FAIR), which is under construction at Darmstadt in Germany, promise new and detailed insights into the nuclear reactions and rare radioactive ion species that underpin the synthesis of heavy elements in the universe.

FAIR is a multipurpose accelerator facility that will provide beams, from protons up to uranium ions, with a wide range of intensities and energies, in addition to secondary beams of antiprotons and rare isotopes. Complementary to CERN's Large Hadron Collider or Super Proton Synchrotron, FAIR is pushing the intensity rather than the energy frontier for hadron beams. It will enable scientists to produce and study reactions involving rare exotic hadronic states or rare, very short-lived radioactive nuclei. It will enable the investigation of processes under the extreme temperatures and pressures that prevail in large planets, stars and stellar explosions. FAIR will also allow physicists to produce and study dense hadronic matter and its transition to quark matter, and permit tests of quantum electrodynamics in the regime of very strong electromagnetic fields, to name but a few goals.

Overall, FAIR's scientific programme comprises hadron physics, nuclear structure and astrophysics, atomic physics, plasma physics, materials research, and radiation biophysics and its applications in cancer therapy and space research. Its science is divided between four main pillars (see p43), including experiments similar in design to those in high-energy physics. After a lengthy and complex phase of development, a groundbreaking ceremony held on 4 July 2017 marked the start of construction of the FAIR facility.

Project evolution

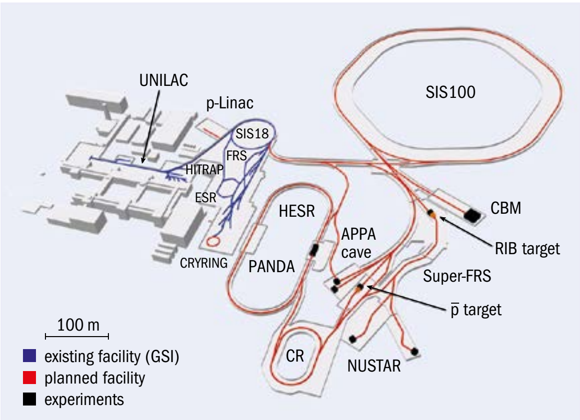
FAIR was developed by the international science community and the GSI laboratory (the Helmholtz Centre for Heavy Ion Research) around the turn of the millennium. GSI, founded in 1969, has a long tradition in nuclear and atomic physics and, more generally, heavy-ion research, and was therefore a natural site on which to develop the next generation of accelerators and experiments for these fields. The initial start date of FAIR was 7 October 2010, when nine partner countries (Finland, France, Germany, India, Poland, Romania, Russia, Slovenia and Sweden) signed an intergovernmental agreement for its construction and operation. The UK joined FAIR as an associate member in 2013.

During late 2014, the then FAIR management reported difficulties surrounding new construction requirements. Although not unusual for a complex, one-of-a-kind facility such as FAIR, this caused major modifications of the civil-construction design and resulted in a delay and cost increase of the overall project. In September 2015 the FAIR Council, representing the nine shareholders, unanimously agreed to adapt the FAIR construction budget and timeline according to the necessary design modifications.

Following this key decision, FAIR was completely reorganised and consolidated: the FAIR and GSI GmbH companies aligned their managerial and administrative structures and processes, ▷

Facility for Antiproton and Ion Research

GSI/FAIR



GSI/FAIR

(Left) The existing GSI accelerators UNILAC, SIS18 and ESR (blue) and the FAIR facilities (red). FAIR comprises the SIS100 synchrotron; the antiproton separator and the super fragment separator (Super-FRS); the collector ring (CR); high-energy storage ring (HESR); and experimental stations for APPA, CBM, NUSTAR and PANDA. The proton linac and the CRYRING also belong to the FAIR instrumentation portfolio. (Right) A rendering of the completed GSI-FAIR facility.

and a joint management team was installed in a stepwise process, with former spokesperson for the ALICE experiment at CERN, Paolo Giubellino, appointed as scientific managing director and spokesperson for FAIR-GSI in January 2017. Thanks to these and other changes, civil-construction work for the tunnel that will house FAIR's main accelerator began on schedule this summer, with the goal to finish all FAIR buildings by the end of 2022. In parallel, procurement of the FAIR accelerator systems and construction of the FAIR detector instrumentation is progressing well. Following the installation and commissioning of the accelerators and experiments starting in 2020/2021, the FAIR science programme is expected to start operation in 2025.

A journey through FAIR

The FAIR accelerator complex is optimised to deliver intense and energetic beams of particles to different production targets. The resulting beams will then be steered to various fixed-target experiments or injected into storage-cooler rings for novel in-ring experiments with beams of secondary antiprotons or radioactive ions at the highest beam qualities. The central machines of FAIR are: the fast-ramping SIS100 synchrotron, which provides intense primary beams; the large-aperture Super Fragment Separator (Super-FRS), which filters out the exotic ion beams; and the cooler storage rings CR and HESR (see the image above). The SIS100 is the heart of FAIR. With a circumference of 1.1 km and a maximum magnetic bending power of 100 Tm, the machine will accelerate ion beams with maximum intensities ranging from 4×10^{13} protons at 29 GeV to 5×10^{11} uranium (28+) ions at 2.7 GeV/u. The existing GSI accelerators UNILAC and SIS18 will serve as injectors and pre-accelerators for SIS100, while a new proton linac will be installed for high-intensity injection into the SIS18/SIS100 synchrotron chain.

FAIR is expected to be the flagship facility for hadron, nuclear and atomic physics until around 2040.

To maximise the luminosity of the SIS100, fast-ramped superconducting superferric magnets with a maximum field of 1.9 T and ramp rates up to 4 T per second have been developed to enable cycle times of the same order as the cooling rates in the storage rings (see image on p44). Together with the upgraded SIS18 pre-accelerator, the SIS100 will provide uranium ion beams 10 times more intense than previously available beams at GSI. The cold machine design has a further advantage: the SIS100 beam pipe enables heavy residual gas components to be pumped, potentially stabilising the dynamic pressure. Due to the tight beam-loss budget, the iron yoke of the superconducting magnets must be built with the highest precision and reproducibility. Production has already started for the SIS100 dipole magnets, and the first beams from SIS100 are foreseen for 2025. Three test facilities at GSI, JINR/Dubna and CERN have been established to assess the different types of superconducting magnets.

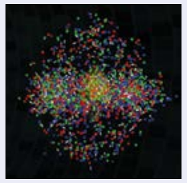
Two production targets for rare isotope and antiproton beams will be served by the SIS100. A primary ion beam can either be slowly extracted to the Super-FRS over a period of many seconds to produce radioactive secondary beams for fixed-target experiments, or it can be extracted quickly in the form of a single, compressed, short bunch to produce a secondary beam of antiprotons or exotic ions. The in-flight-generated rare isotopes, produced via projectile fragmentation of all primary beams up to uranium-238 or alternatively via fission of uranium-238 beams, are efficiently separated in the large aperture of the Super-FRS. Due to the large acceptance of this machine, the gain in primary-beam intensities for uranium ions in the SIS100 translates into a factor of more than 1000 for secondary-beam intensities of rare, radioactive isotopes.

After production and separation, the hot secondary ion beams drive three experimental scenarios: they can be stopped to allow studies of their ground-state properties; used in in-flight and ▷

FAIR's four scientific pillars

Atomic and Plasma Physics, and Applied sciences (APPA)

With about 700 participants, APPA is an umbrella for several sub-collaborations working across atomic physics, plasma physics and applied sciences, with specific programmes in biophysics, medical physics and materials science. Several experimental stations, in addition to the CRYRING and HESR storage rings and the trapping facility HITRAP, will allow the APPA community to tackle a variety of challenges. In atomic physics, for example, high-precision tests of bound-state QED in the non-perturbative regime become possible. A precise determination of fundamental constants such as the fine-structure constant is also a target, which involves very precise measurements of the bound-state g-factors in medium to high-Z hydrogen-like ions confined in a trap. Plasma physicists will be able to create and probe dense plasmas to test models of planetary and stellar structure. By means of FAIR beams, the high-energy component of galactic cosmic radiation can also be simulated to assess the risk of space missions for astronauts and electronic equipment by dedicated irradiation experiments. Finally, the material science and geoscience communities will be able to test how materials respond to the simultaneous application of irradiation and pressure, which is of interest for the synthesis of new materials from highly non-equilibrium conditions and for understanding processes in the Earth's mantle.



The Compressed Baryonic Matter experiment (CBM).

The CBM experiment, which has more than 500 participants and is organised similarly to the LHC experiments at CERN, will use high-energy nucleus–nucleus collisions to investigate highly compressed nuclear matter. The fixed-target experiment is 10 m long and comprises a large-aperture superconducting dipole magnet and seven subsequent detector systems providing tracking and particle identification. CBM collisions will recreate the matter densities found in supernova explosions, the cores of neutron stars and neutron-star mergers. In contrast to the very high temperatures and low net-baryon densities reached at the Relativistic Heavy Ion Collider in Brookhaven and the LHC at CERN (conditions that are similar to the conditions that prevailed microseconds after the Big Bang), the energies of the FAIR beams are perfectly suited to study the QCD phase diagram of strongly interacting matter at large net baryon densities and low temperatures. Here, it is expected that the QCD phase diagram exhibits a rich structure such as a critical point, a first-order phase transition between hadronic and partonic matter, or new phases such as quarkyonic matter. Discovering these landmarks would be a breakthrough in our understanding of the strong interaction. The CBM experiment is designed to run at interaction rates of up to 10 MHz, which is 3–4 orders of magnitude higher than the rates reached in other high-energy heavy-ion experiments. It has very fast and radiation-hard detectors, a novel data read-out and analysis concept, and a high-performance computing cluster for online event reconstruction and selection.

The PANDA experiment

The antiProton ANnihilation in DArmstadt (PANDA) collaboration is a co-operation of more than 400 scientists from 19 countries, similar to but smaller than the LHC experiments at CERN. Its goal is to understand hadrons using the power of an antiproton beam on fixed hydrogen or other nuclear targets. Antiproton–proton annihilations have enormous advantages compared to proton–proton collisions, such as small momentum-transfer at maximum released energy with well-defined initial states and high-precision mass scanning. The vast difference in mass between the proton and its individual quark constituents is a result of the binding among quarks in the confinement regime, and exotic hadrons such as tetra- and pentaquarks, hybrids and glueballs will reveal uncharted properties of this binding. PANDA will use proton form-factor measurements, deep virtual Compton scattering and quark dynamics, as well as the behaviour of hadrons inside nuclear media, as highly complementary tools with which to understand the very nature of hadrons. Strange quarks in hyperons, for instance, can be used as tags to trace quark dynamics with very high cross-sections and spin degrees of freedom. The PANDA experiment features a modern multipurpose detector with excellent tracking, calorimetry and particle-identification capabilities. Together with the high-quality antiproton beam at FAIR's high-energy storage ring (HESR), an unprecedented annihilation rate and sophisticated event filtering, it will be ideally suited to address important questions in all aspects of this field.

NUclear STructure, Astrophysics and Reactions (NUSTAR)

The NUSTAR collaboration at FAIR has more than 800 participants from 180 institutes located in 38 countries. Similar to APPA, NUSTAR does not represent a single monolithic experiment but is structured in several sub-collaborations across different experimental set-ups tailored to various aspects of secondary radioactive ions, such as mass and lifetime measurements. A major goal of NUSTAR is to improve our knowledge of the synthesis and abundance of chemical elements, for which the collaboration will explore the structure and reaction properties of very rare radioactive ions produced for the first time by FAIR. Although much has been learnt about the behaviour of stable and unstable nuclei in past decades, we are still far from understanding how the very heavy elements are formed through reactions involving rare nuclei at the limit of stability. FAIR will allow scientists to artificially produce the nuclei that occur as radioactive intermediate products in the formation of stable isotopes, measuring directly in the laboratory the different processes involved. FAIR offers unique tools for such studies. The Super-FRS will make very efficient use of the highly intense beams at high energies to separate beams of the heaviest and most neutron-rich nuclei, while FAIR's complex network of storage rings will allow mass and lifetime measurements. This will place NUSTAR at the forefront of this branch of science. Many of NUSTAR's experimental set-ups are already complete, and the collaboration plans to transfer them into the new buildings starting from 2023.

Facility for Antiproton and Ion Research

Babcock Noell GmbH

The newly developed fast-cycling superconducting dipole magnet for FAIR's SIS100 synchrotron.

secondary reactions to produce even more exotic species; or stored and pre-cooled in the collector ring (CR). The fast stochastic cooling process in the CR relies on a fast de-bunching of the injected short bunch. Pre-cooled secondaries will then be transferred from the CR to the high-energy storage ring (HESR), where they can be accumulated and accelerated up to an energy of 15 GeV for antiprotons and about 5–6 GeV/u for very heavy ions. The HESR can also store and cool stable high-charge-state heavy-ion beams, directly injected from the SIS100 via the CR, for precision studies in atomic, nuclear and fundamental physics, such as tests of quantum electrodynamics (QED) in strong fields or tests of special relativity.

FAIR science ahead

About 3000 scientists including more than 500 PhD students from around the world will carry out experiments at FAIR to understand the fundamental structure of matter, explore its exotic forms, and to understand how the universe evolved from its primordial state. FAIR's science programme is structured into four pillars and organised in four large collaborations with several hundred members each: APPA, serving communities in atomic, plasma physics and applications; CBM, the Compressed Baryonic Matter experiment; NUSTAR, the NUclear STructure, Astrophysics and Reactions programme; and PANDA (antiProton ANihilation in DArmstadt), which aims to study hadrons using antiproton beams. APPA and NUSTAR consist of several sub-collaborations, while CBM and PANDA are rather monolithic experiments involving large detectors (see panel on previous page).

Well before the start of the SIS100 operation in 2025, an upgrade of the GSI accelerators due for completion this year will allow extensive testing of FAIR components. This upgrade will also allow researchers to trial novel FAIR instrumentation for an attractive intermediate research programme, named FAIR phase 0. For instance, the NUSTAR "R3B" spectrometer, the CRYRING and the HITRAP facility will be available and will enable, in combination with the intensity-upgraded SIS18 synchrotron and GSI's fragment separator, novel experiments in nuclear structure and reactions in so far unexplored areas of the nuclear chart.

The CRYRING and the HITRAP facility will enable physicists to further increase the precision of both atomic-physics measurements of QED effects in highly charged heavy ions and of measurements of fundamental constants. Moreover, the hadronic-matter experimental programme of HADES (High Acceptance Di-Electron Spectrometer) will benefit from the higher intensities from the SIS18. HADES is a versatile detector for the study of dielectron (e^+e^-) and hadron production in heavy-ion collisions, as well as in proton- and pion-induced reactions in the energy range of 1–4 GeV. These are just a few examples from the intermediate research programme, which will start in 2018 and offer about three months of beam time per year, thereby bridging the gap until the commissioning of the SIS100.

The FAIR phase 0 programme intends to maintain and further establish the FAIR-GSI community by offering attractive science before the full complex is up and running. It will also educate and train the next generation of scientists and engineers for FAIR and, last but not least, maintain and extend the technical skills required to operate such a large accelerator complex. While FAIR phase 0 is an important and necessary step offering new and excellent research opportunities for users, full exploitation of the unique science potential opened up by FAIR has to await the start of SIS100 operation in 2025.

Depending on how rich the scientific harvest from FAIR will be and in which specific directions it will be most prominent, one can conceive of several upgrade options. One is a further increase of intensities by up to two orders of magnitude for nuclear structure, reactions and astrophysics, which will also benefit dense-plasma research. Another option is a further increase of beam energy by a factor of 3–6 for hadron- and quark-matter research. Other upgrade possibilities include strengthening the antiproton research programme, via cooled low-energy antiproton beams, for the study of fundamental interactions and symmetries. FAIR is expected to be the flagship facility for hadron, nuclear and atomic physics – as well as related science fields exploiting intense beams of antiprotons and heavy ions – until around 2040.

Résumé

L'avenir de FAIR se dessine

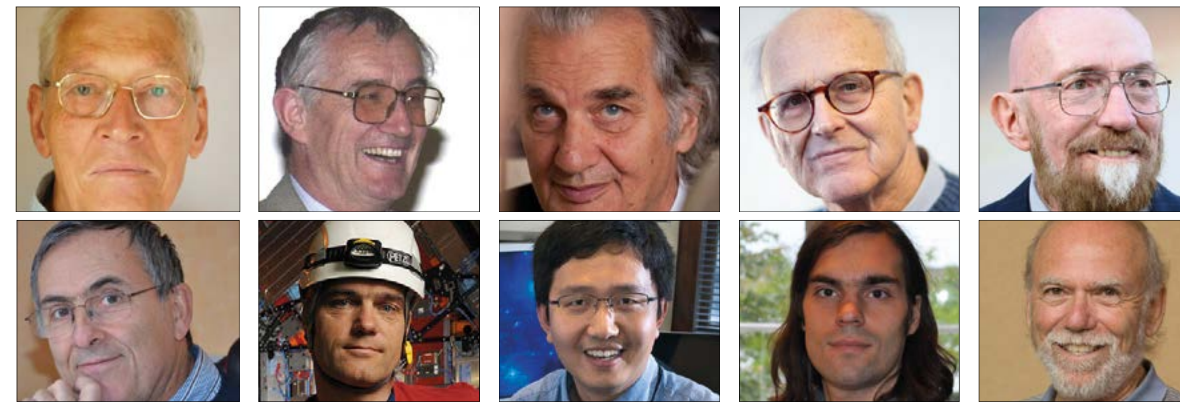
Une cérémonie a eu lieu le 4 juillet pour marquer le début des travaux de construction de l'installation européenne de recherche sur les antiprotons et les ions (FAIR) auprès du laboratoire GSI de Darmstadt (Allemagne). FAIR fournira à plusieurs expériences différentes des faisceaux d'une vaste gamme d'intensités et d'énergies constitués de particules allant des protons aux ions uranium. L'installation fournira aussi des faisceaux secondaires d'antiprotons et d'isotopes rares. Le programme scientifique de FAIR comprend la physique des hadrons, la physique atomique et la physique des plasmas, la recherche sur les matériaux et la biophysique des rayonnements. Ce programme, qui s'appuie sur les fondamentaux du laboratoire GSI, devrait débuter en 2025.

Oliver Boine-Frankenheim and **Christina Trautmann**, TU Darmstadt and GSI Darmstadt; **Peter Senger**, GSI Darmstadt and University of Frankfurt; **Nasser Kalantar-Nayestanaki**, University of Groningen; **Klaus Peters**, University of Frankfurt and GSI Darmstadt; and **Klaus-Dieter Gross**, GSI Darmstadt.

Faces & Places

AWARDS

EPS awards prizes for high-energy physics



2017 EPS prizewinners, clockwise: Erik Heijne, Robert Klanner, Gerhard Lutz, Rainer Weiss, Kip Thorne, Barry Barish, Simon Caron-Huot, Xin Qian, Michael Hoch and René Brun.

The high-energy and particle-physics division of the European Physical Society (EPS) has announced the winners of its 2017 prizes, awarded at the EPS Conference on High-Energy Physics held in Venice on 5–12 July.

The 2017 High Energy and Particle Physics Prize for an outstanding contribution to the field was awarded to Erik Heijne of Czech Technical University in Prague, Robert Klanner of the University of Hamburg and DESY, and Gerhard Lutz of the Max Planck Institute for Physics, "for their pioneering contributions to the development of silicon microstrip detectors that revolutionised high-precision tracking and vertexing in high-energy physics experiments". At the end of the 1970s, the trio developed the first silicon-strip counters for particle physics using the NA11 and NA32 experiments at CERN. Gerhard Lutz sadly passed away aged 77 in April this year (see p56).

The 2017 Giuseppe and Vanna Cocconi Prize for an outstanding contribution to particle astrophysics and cosmology goes to Rainer Weiss of MIT and to Kip Thorne and Barry Barish of Caltech, "for their pioneering and leading roles in the LIGO observatory that led to the direct detection of gravitational waves, opening a new window to the universe". LIGO has recently detected its third gravitational-wave event, and a global effort is mounting to build further such observatories (see p11).

Theorist Simon Caron-Huot of McGill University has won the 2017 Gribov Medal for outstanding work by a young physicist in theoretical particle physics and/or field theory, "for his groundbreaking contributions to the understanding of the analytic structure of scattering amplitudes and their relation to Wilson loops". The Young Experimental Physicist Prize for outstanding work by a young physicist, meanwhile, was won by Xin Qian of Brookhaven National Laboratory, "for his key contributions to the Daya Bay Reactor neutrino experiment that led to the measurement of the neutrino mixing angle θ_{13}".

The 2017 Outreach Prize was awarded to Michael Hoch, who is a member of the CMS collaboration, "for initiatives highlighting the conceptual and physical beauty of high-energy physics, and the inspirational qualities that are common to both art and science". Finally, the 2017 Special Prize of the EPS high-energy and particle-physics division was awarded to René Brun of CERN, "for his outstanding and original contributions to the software tools for data management, detector simulation, and analysis that have shaped particle and high-energy physics experiments for many decades". Brun pioneered the GEANT3 detector-simulation system, co-ordinated the development of the PAW (Physics Analysis Workstation) platform, and in 1995 created the ROOT system while working for the NA49 heavy-ion experiment.

High recognition for CERN Director-General

On 20 June, CERN Director-General Fabiola Gianotti was received as a Foreign Associate of the French Academy of Sciences in Paris. Established in 1666, the Academy has 262 members and 138 foreign associates. Also in June, she received an honorary doctorate from the University of Roma Tor Vergata and also the 2017 Tomassoni Prize from the University of Roma La Sapienza, "for the innumerable contributions to particle physics that led her to play a leading role in discovering the Higgs boson as spokesperson of the ATLAS experiment and in the orientation of current and future research as DG of CERN". The prize money will be donated to the CERN & Society Foundation for educational programmes.

Juliette Agnel

Fabiola Gianotti has been elected Foreign Associate of the French Academy of Sciences, among two further recent recognitions.

Two schools win beam time at CERN

N Caraban Gonzalez

One of last year's winning teams setting up an experiment.

On 13 June, CERN announced the winners of its 2017 Beamline for Schools competition. Selected from 180 team entries from 43 countries, totalling around 1500 high-school students, the winners were "Charging Cavaliers" from École secondaire catholique Père-René-de-Galinée in Cambridge, Canada, and "TCO-ASA" from the Liceo Scientifico Statale "T C Onesti" in Fermo, Italy. In September the teams will come to CERN to carry out their own experiments at a fully equipped CERN beamline. Charging Cavaliers, comprising 13 students, plans to search for elementary particles possessing fractional charge by observing their light emission in the same type of liquid scintillator as that used in the SNO+ experiment at SNOLAB, Canada. Team TCO-ASA, comprising eight students, has chosen to build a Cherenkov detector at its school and wishes to test it in a real particle beam.

The first Beamline for Schools competition was launched in 2014 on the occasion of CERN's 60th anniversary. To date, winners from the Netherlands, Greece, Italy, South Africa, Poland and the UK have performed their experiments at CERN.

2017 GÉANT Community Awards

GÉANT is a fundamental element of Europe's e-infrastructure, delivering a high-bandwidth and high-speed fibre-optic backbone for Europe's national research and education centres. Since 2012, the GÉANT Community Awards have honoured individuals who have contributed significant ideas, time and expertise to the development of the network. The 2017 awards were presented at the TNC17 networking conference in Linz, Austria.

Massimo Parovel of the Music Conservatory Giuseppe Tartini, Trieste, had the idea to enable performing artists to interact even if they are located thousands of kilometres apart, resulting in a low-latency audiovisual system called LOLA that is now being used for events and educational purposes. Husband-and-wife team Tomasz Wolniewicz and Maja Górecka-Wolniewicz of PSNC and Nicolaus Copernicus University shared an award for their work on the eduGAIN service infrastructure, the eduroam Configuration Assistant Tool and other activities. Finally, Hannah Short of CERN's IT department was commended for making signficant contributions through her leadership of work in the REFEDS and AARC project communities on Sirtfi (Security Incident Response Trust Framework for Federated Identity), which enables incident response to be co-ordinated across federated organisations.

GÉANT

(Left to right) The four prizewinners Massimo Parovel, Hannah Short, Maja Górecka-Wolniewicz and Tomasz Wolniewicz.

EVENTS

SESAME celebrates opening

N Caraban Gonzalez/CERN

King Abdullah II (centre) flanked by heads of the delegations of the SESAME members and directors of international organisations that have supported SESAME.

On 16 May the SESAME light source in Jordan was officially opened by King Abdullah II, marking a new era of research in the region covering fields ranging from medicine and biology, through materials science, physics and chemistry to healthcare, the environment and archaeology.

An intergovernmental organisation, SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East) is the first regional laboratory for the Middle East and neighbouring regions. It is based around a 42 m-diameter storage ring in which electrons generate intense beams of synchrotron light for diverse user experiments. First turns of the electrons took place in January, and SESAME's initial research programme with three beamlines will be operational this year.

CERN has played a major role in the facility, notably through the European Commission-funded CESSAMag project, which provided the magnet system for SESAME's main ring and brought CERN's expertise in accelerator technology to the project.

The May ceremony also saw a changeover in SESAME's organisation, with former CERN Director-General Rolf Heuer succeeding fellow former CERN Director-General Chris Llewellyn Smith as the new president of the SESAME Council. "SESAME truly embodies the spirit of scientific curiosity and collaboration that is the driving force of human progress," said Fabiola Gianotti, Director-General of CERN, at the event. "CERN and SESAME have this in common: both were established to provide a centre of scientific excellence and to foster collaboration among neighbours."

UK hosts third HL-LHC industry day

The third edition of the High Luminosity LHC (HL-LHC) Industry Day took place in Warrington, a few minutes away from Daresbury Laboratory in the UK, on 22–23 May. The two-day event, jointly organised by CERN and the Science and Technology Facilities Council (STFC), gathered some 200 participants from 17 European countries. Key engineers and physicists from CERN and STFC presented the technical challenges of the HL-LHC project to numerous company delegates attending the event. The face-to-face meetings arranged with the CERN engineers were also an excellent opportunity for companies to learn more about the key components of the HL-LHC upgrade and the upcoming calls for tenders.

The HL-LHC will allow the LHC to achieve instantaneous luminosities a factor five larger than its nominal value, and the project's estimated CHF950 million cost will be realised within a constant CERN budget. The HL-LHC study phase started in 2010 and the commissioning phase will finish in 2026. The upgrade is crucial not only for the full exploitation of the LHC's physics potential, but also to enable operation of the collider beyond 2025. More than 1.2 km of the present LHC plus associated technical infrastructure will be renewed – a challenge that can only be accomplished with the strong involvement of European industry. Since 2012, the HL-LHC has therefore organised events to connect CERN with potential industrial partners that can meet the specific technical challenges.

C Noels/CERN

Collaboration with industry is key to realising the HL-LHC project.

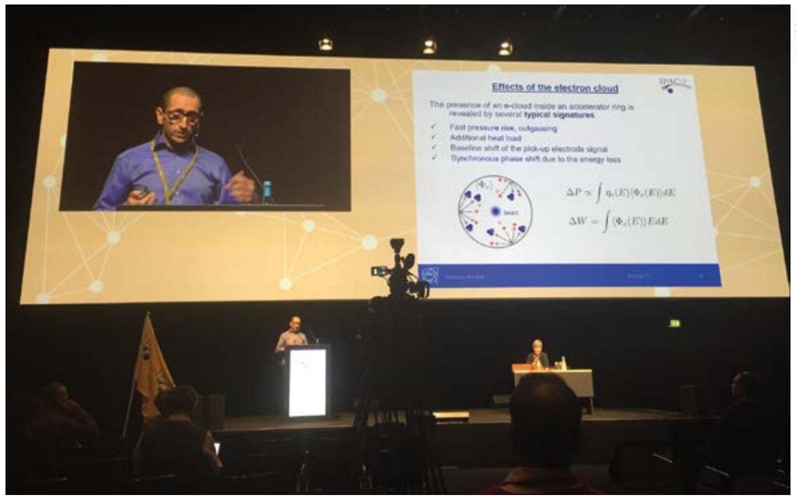
CONFERENCES

Accelerator experts meet in Copenhagen

The 8th International Particle Accelerator Conference (IPAC) took place in Copenhagen, Denmark, on 14–19 May and was attended by more than 1550 participants from 34 countries. Hosted by the European Spallation Source (ESS) and organised under the auspices of the European Physical Society (EPS) accelerator group and the International Union of Pure and Applied Physics, the event was also supported by the MAX-IV facility and Aarhus University.

Although accelerators were initially developed to understand the infinitesimal constituents of matter, they have evolved into sophisticated instruments for a wide range of fundamental and applied research. Today, particle accelerators serve society in numerous ways, ranging from medicine and energy to the arts and security. Advanced light sources are a case in point, following the steady improvement in their performance in terms of brilliance and temporal characteristics. MAX-IV and the ESS, which lie just across the Oresund bridge in Sweden, are two of the most powerful instruments available to life and material scientists, and are operating and under construction, respectively. Meanwhile, the most brilliant source of ultra-short flashes of X-rays – the European X-ray Free Electron Laser at DESY in Hamburg – has recently achieved first lasing and will soon be open to users (see p18). Another X-ray free-electron laser, the SwissFEL at PSI, has just produced laser radiation for the first time in the soft X-ray regime and aims to achieve smaller wavelengths by the end of the year. New synchrotron light sources have also come into operation, such as the SOLARIS synchrotron in Poland, and major upgrades to the European Synchrotron Radiation Facility in France based on a new lattice concept are planned.

Particle physics remains one of the main drivers for new accelerator projects and for R&D in IPAC's many fields. The big brother of all accelerators, CERN's LHC, performed outstandingly well during 2016, exceeding nominal luminosity by almost 50% thanks to operations with more tightly spaced bunches and due to the higher brightness of the beams delivered by the LHC injectors. Mastering the effects of electron clouds and carrying out progressive "scrubbing" of the surfaces of the LHC beam screens have been key to this performance. Achieving nominal luminosity marks the completion of one of the most ambitious projects in science and bodes



N Iida/KEK

CERN's Giovanni Rumolo presented an overview of electron-cloud effects at the LHC.

well for the High Luminosity LHC upgrade programme now under way. IPAC17 also heard the latest from experiments at CERN's Antiproton Decelerator facility, including the trapping and subsequent spectroscopic measurements of antihydrogen atoms and the exciting studies that will still be carried out using the new ELENA facility there.

Impressive progress

On the lepton machine front, the Super KEKB electron–positron collider at KEK in Tsukuba, Japan, was successfully commissioned with beam in 2016. The superconducting quadrupoles and correctors of the final focusing system and the BELLE II detector are being installed, and commissioning with beam is due to be completed in 2018 when first data are also expected. Concerning the quest for higher-energy circular and linear electron–positron colliders, the main accelerator technology choices for the Compact Linear Collider (CLIC) have recently been validated at CERN's CTF3 test facility, and the gradient of CLIC's two-beam acceleration principle has been established beyond 100 MV/m. There has also been impressive progress in the design of a very large high-luminosity circular electron–positron collider in the frame of the Future Circular Collider design study, while corresponding studies for a future hadron–hadron collider at CERN and similar studies are also under way in China.

Making progress at the high-intensity and high-energy frontiers demands continuous advances in accelerator technology, and superconductivity is vital for high-field magnets and high-gradient RF cavities for continuous-wavelength operation. Normal conducting RF structures operated at high frequency are also achieving new performance records, demonstrating accelerating gradients up to 120 MV/m, and this technology is attracting the attention of several laboratories keen to build compact free-electron lasers. In the field of novel accelerator concepts, a new scheme to produce very low-emittance muon beams based on the interaction between a 45 GeV positron beam and a thin target has been devised by researchers at INFN Frascati. Finally, with increasing attention to the energy efficiency of accelerators, major steps are being made in the domain of high-efficiency RF sources, where efficiencies of up to 85% were reported at this year's IPAC event.

The Copenhagen conference saw 115 companies from 16 countries present their products as part of an industrial exhibition, which was complemented by lively panel discussions on industrial careers, intellectual property and other relevant issues. In total there were 45 invited and 51 contributed oral presentations and approximately 1400 posters, with the EPS accelerator group also awarding its 2017 prizes (*CERN Courier* April 2017 p38). The 9th IPAC will take place in Vancouver, Canada on 29 April– 4 May 2018.

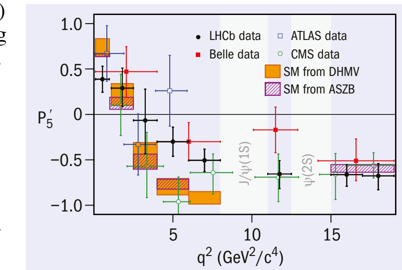
LHC physics shines in Shanghai

SJTU

The Large Hadron Collider Physics (LHCP) conference took place at Shanghai Jiao Tong University (SJTU) in China, on 15–20 May. One of the largest annual conferences in particle physics, the timing of LHCP2017 chimed with fresh experimental results from the ALICE, ATLAS, CMS and LHCb experiments based on 13 TeV LHC data recorded during 2015–2016. The conference saw many new results presented and also offered a broad overview of the scientific findings from Run 1, based on lower-energy data.

One of the main themes of the conference was the interplay between different results from various experiments, in particular those at the LHC, and the need to continue to work closely with the theory community. One such example concerns measurements of rare B-meson decays and in particular the decay $B^0 \rightarrow K^* l^+ l^-$, which is sensitive to new physics and could probe the presence of new particles through the study of the B^0 helicity structure. The LHCb collaboration has found several discrepancies with Standard Model (SM) expectations, including a more than three standard-deviation discrepancy in the angular distributions of this B^0 decay. New results presented by ATLAS and CMS have created further tension in the situation (see diagram), and more data from LHC Run 2 and continued theoretical developments will be critical in understanding these decays.

An exciting result from the ALICE



(Top) LHCP2017 had 460 participants representing more than 200 institutions in 30 countries. (Above) The so-called P_5' angular observable for $B^0 \rightarrow K^* l^+ l^-$ decays versus the dilepton invariant mass, as measured by LHCb (JHEP **2** *104), Belle (*Phys. Rev. Lett. ***118*** *111801), ATLAS (ATLAS-CONF-2017-023) and CMS (CMS-PAS-BPH-15-007).*

experiment showed a surprising enhancement of strange-baryon production in proton–proton collisions (*CERN Courier* June 2017 p10). In nucleus–nucleus collisions, this enhancement is interpreted as a signature of the formation of a quark–gluon plasma (QGP) – the extreme state that characterised the early universe before the appearance of hadrons. The first observation of strangeness enhancement in high-multiplicity proton–proton collisions hints that the QGP is also formed in collisions of smaller systems and opens new directions for the study of this primordial state of matter.

From the Higgs sector, CMS reported an observation of Higgs decays to two particles with a significance of 4.9 standard deviations compared to SM backgrounds. Differential cross-sections for Higgs decays to two Z bosons, which test properties of the Higgs such as its spin and parity and also act as a probe of perturbative QCD, were shown by ATLAS. Throughout the conference, it was clear that precision studies of the Higgs sector are a critical element in elucidating the nature of the Higgs boson itself, as well as understanding electroweak symmetry breaking and searching for physics beyond the SM.

In addition to these highlights, a broad spectra of results were presented. These ranged from precision studies of the SM, such as new theoretical developments in electroweak production, to numerous new search results, such as searches for low-mass dark-sector mediators from the CMS experiment and searches for supersymmetry in very high-multiplicity jet events for ATLAS. The conclusion from the conference was clear: we have learnt a tremendous amount from the Run 2 LHC data but are left with many open questions. We therefore eagerly await the newest data from the LHC to help further dissect the SM, cast light on the nature of the Higgs, or to find an entirely new particle.

Exploring axions and WIMPs in Greece

On 15–19 May, the historic Greek city of Thessaloniki hosted the 13th annual edition of the Patras Workshop on Axions, WIMPs and WISPs. Since the first meeting in 2005, the event has evolved into an important annual conference of the astroparticle community, addressing questions related to dark matter and dark energy both from the experiment and theory sides. Related topics from neutrino or astrophysics complement the agenda. An all-time high of more than 120 scientists attended the workshop this year, indicating the ever-growing interest in the quest for dark matter and especially for axions.

As well-established dark-matter candidates, along with weakly interacting massive particles (WIMPs), axions and axion-like particles (ALPs) are a central topic of the workshop. A large number of ongoing, planned and proposed experiments cover the full axion mass range with a good chance of detection. The most stringent experimental bounds on axion-to-photon couplings still come from "helioscopes" such as the CAST experiment at CERN, which use large magnets to convert axions produced in the Sun to detectable X-ray photons. New proposals discussed at the workshop aim at improving the sensitivity of experiments but also at extending their reach to dark-matter axions and dark-energy candidates such as chameleons (scalar particles that change their coupling strength in response to the local matter density). Dedicated chameleon searches were presented, exploiting both their coupling to photons and to matter, the latter using a novel opto-mechanical detector.

Dark-matter axions are the target of "haloscopes", which search for relic axions in the galactic halo using ultra-cold resonant microwave cavities immersed in a magnetic field. Various techniques to reach higher frequencies and to move the axion-mass ▷

Vertoo

Participants of PATRAS2017, which focuses on the low-energy, high-intensity frontier.

coverage to the meV region are under study, and first results on axion masses up to around 24 μeV were reported by the HAYSTAC collaboration. Other projects aim at reaching even higher masses: multi-vane cavities, distributed Bragg reflectors, photonic band-gap resonators and multi-layered dielectric discs. These experiments employ cutting-edge superconducting technology and use amplifiers developed for quantum-computing research. Superconducting cavities that can achieve quality factors as high as 10^6 and ultra-high field magnets (up to 25 T) are also being developed at IBS/CAPP in Korea.

On the theory side, talks ranged from axions in string theory to estimates of the axion mass using the tools of lattice QCD. Several contributions focused on the observed anomalous transparency of the universe for high-energy photons, which might be explained by processes involving ultra-light ALPs with masses in the neV region or below. Others discussed whether the current density of dark-matter axions might differ from the homogeneous canonical picture due to the presence of axion condensates, caustics and mini-clusters.

A plethora of experiments aim at the direct detection of feeble WIMP-induced nuclear recoils. WIMPs are one of the prime candidates for cold dark matter because they arise naturally in various theories beyond the Standard Model of particle physics. The search strategy differs slightly for low- and high-mass WIMPs, with the transition taking place at around 5 GeV/c^2, but all efforts rely on ultra-low backgrounds and low thresholds. The Patras event saw detailed reports from almost a dozen running and upcoming projects – a highlight being the first public presentation of new results from the XENON1T dark-matter experiment, which has set the most stringent limits on WIMP-nucleon scattering above WIMP masses of around 10 GeV/c^2 (see p10). WIMP physics can also be probed indirectly, for instance by the Fermi telescope, and by colliders such as the LHC. It is now clear that, while the simplest WIMP models are under some pressure given the non-detection so far, plenty of well-motivated parameter space remains.

There are also a number of promising fixed-target experiments looking for portals from the dark sector to the Standard Model, such as dark photons, and other subtle experiments to study the low-energy, high-intensity frontier. In this frame, the community can look forward to developments with CERN's "Physics Beyond Colliders" initiative (*CERN Courier* November 2016 p28) and the US "Cosmic Vision" initiative.

Berlin meeting weighs up post-LHC machine

S Bennett/CERN

Participants at the 3rd FCC collaboration meeting in Berlin.

From 29 May to 2 June, more than 500 participants attended the 3rd Future Circular Collider (FCC) collaboration week in Berlin, Germany. The meeting heralds a new phase for the FCC collaboration, which will now start preparing a design report and cost estimates for all collider options, to be delivered by the end of 2018. The vibrant and global R&D programme of FCC paves the way for future energy and intensity-frontier colliders that could replace the LHC by the mid-2030s. Impressive progress is being made across all domains of the FCC study, and the large number of young researchers involved is highly promising for the future of the field.

In view of the long lead times of major projects in high-energy physics, the FCC study is exploring several possible options for post-LHC circular colliders. For CERN to retain its pole position in accelerator-based particle physics – as said by CERN Director-General Fabiola Gianotti in her opening address – the laboratory "must continue to play a leading role in global efforts to develop technologies and design future colliders that could succeed the LHC in the medium-to-long term". The formidable feat of creating the next LHC – a machine that offers significant increases in energy and luminosity compared with today's machines – also requires new levels of global co-operation.

The FCC study envisions an accelerator complex that would offer a rich physics programme far into the 21st century. Specifically, the study explores concrete plans for an energy-frontier hadron collider (FCC-hh) and a luminosity-frontier lepton collider (FCC-ee) housed in a new 100 km-circumference tunnel in the Geneva region. The study also includes an electron–hadron collider (FCC-he) and examines the option of a high-energy upgrade of the LHC (HE-LHC) that could double the present energy reach. FCC week 2017 reviewed progress across the different study domains. Revised layouts of accelerators and detectors were reviewed both for the proton and the lepton machines, and a new reference layout based on a 97.75 km-circumference tunnel was presented. The many rich physics opportunities opened by FCC, along with the possible synergies and complementarities of the different machines, were also discussed in great depth.

Breakthrough technologies

The collider scenarios explored in the FCC study pose a number of technological challenges. The FCC Week 2017 witnessed a growing worldwide eagerness from the scientific and engineering communities, with participants discussing technological and manufacturing breakthroughs that can help to meet the FCC's performance and cost goals. As the CERN director for accelerators and technology, Frédérick Bordry, remarked: "Designing and building a post-LHC accelerator should be based on the use of breakthrough technologies to provide the beam energy, intensity and brightness that are required for a future discovery machine. The ongoing FCC R&D programme is a natural extension of the High-Luminosity LHC activities and it ensures the efficient use of past investments."

The key to reaching the highest energies is the development of new superconducting magnets able to reach dipole fields of 16 T, roughly twice that of the LHC. Significant advances in superconductors, superconducting RF technologies and RF power sources are needed, as is a new beam vacuum system to meet the challenges of going to higher energies. Good progress towards the CDR has been made for other systems, including cryogenics and the supply of electricity.

FCC Week 2018 will take place in Amsterdam and will be the final meeting before the presentation of the Conceptual Design Report scheduled for the end of 2018. By then, results from the second round of the LHC should provide another crucial input needed by the global high-energy physics community to decide on the next generation of colliders.

Visits

S Bennett/CERN

On 16 May, 12 European astronauts visited CERN on a trip organised by Claude Nicollier and Samuel Ting, taking in the AMS control centre.

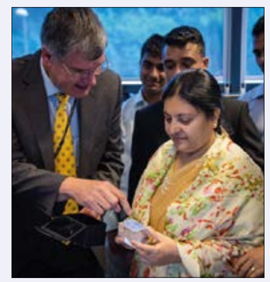
On 8 June, **Jānis Reirs**, minister for welfare, Republic of Latvia (second from left), visited CERN, taking a tour of the Synchrocyclotron and CMS.

Carl Selig

J Ordan/CERN

President of the Republic of Mauritius, Dr **Ameenah Gurib-Fakim**, visited CERN in the morning of Friday 16 June and toured the Synchrocyclotron and the ATLAS experiment before signing the guestbook. She is pictured with (centre) Markus Nordberg, head of resources development at CERN, at the IdeaSquare facility.

Bidya Devi Bhandari, president of the Federal Democratic Republic of Nepal, came to CERN on 16 June. She visited the Synchrocyclotron and the ATLAS control room,and is pictured here with former ATLAS spokesperson Dave Charlton.



J Ordan/CERN

Obituaries

Cécile DeWitt-Morette 1922–2017

Cécile DeWitt-Morette, founder of the Les Houches summer school, passed away on 8 May at the age of 94. Born in Caen, she studied in Paris after completing her bachelor degree. In 1944 her mother, sister and grandmother were killed in the Allied bombing of Caen, but in Paris she secured a job at CNRS and was awarded a PhD three years later with a thesis about meson production. She was then invited to the Institute for Advanced Study in Princeton by Robert Oppenheimer, where she met her future husband, the US physicist Bryce DeWitt (they would go on to have four daughters).

Mixing with the best of US physics made her realise the poor situation of the field in France, especially particle physics, and drove her to do something about it. Precisely at that time, a summer school was organised at the university of Michigan in Ann Arbor, and Cécile had the idea to create such an event in France. Her beautiful eyes with double-iris rings and considerable powers of persuasion, not to mention a fantastic intuition for selecting the best possible lecturers, were difficult to resist. She had a friend whose father, the architect Albert Laprade, loaned her a piece of land at La Côte des Chavants, just above the village of Les Houches in the Arve valley, among farms and cottages. Financial input soon followed thanks to her skilful negotiating tactics, and in the summer of 1951 I was one of a few candidates to attend the school for a period of three months. She had chosen fantastic professors: Léon Van Hove for quantum mechanics and Viki Weisskopf for nuclear physics, both of whom would be future Director-Generals of CERN; Res Jost for field theory; Walter Kohn (a future Nobel Prize winner) for solid state physics; plus seminars by giants such as Wolfgang Pauli. We worked very hard, except for some excursions in the mountains, and learnt a lot.

Cécile DeWitt-Morette founded the Les Houches summer school.

The Les Houches school, of which Cécile remained director for 22 years, continued to be a complete success. Many of its students and some teachers received the Nobel prize, the Wolff prize or the Fields Medal. Among them were Pierre Gilles De Gennes and Claude Cohen-Tannoudji. The demand for basic courses dissipated over the years, but the school became a place for high-level specialised topics, and continues to be so.

Cécile also played an important role in founding the Institut des Hautes Scientifiques (IHES) in Bures sur Yvette, and did important work on functional integration, also collaborating with her mathematical-physicist husband. They were professors at the University of North Carolina at Chapel Hill and at the University of Texas at Austin, successively. Bryce died in 2004 just as he was about to receive the Einstein Prize from the American Physical Society.

I met Cécile for the last time at IHES in 2011 where she was made Officier De la Légion d'Honneur. On 7 May, the day before she died, I understand that she was delighted to learn that the anti-European candidate as president of France, Marine Le Pen, had been defeated.

● *André Martin.*

Charles Gruhn 1935–2017

Charles Gruhn, a long-time colleague and friend for many of us at CERN and elsewhere, passed away peacefully on 24 March. Chuck, as he was known, obtained his PhD from the University of Washington, Seattle, in 1961, and throughout his professional life he worked on the development of particle detectors and their associated electronics.

Chuck started his scientific career at the Massachusetts Institute of Technology, where he worked on nuclear reactions and on studies involving alpha particles, and in 1964 he moved to Michigan State University. His development of detectors included lithium-germanium counters, silicon semiconductors and a Ge(Li) Compton spectrometer. He also performed a large variety of proton-scattering experiments.

U Gruhn

Chuck worked for most of his life on experiments at CERN.

In 1970 he took a sabbatical at the Max Planck Institute for Physics in Munich, which was working in close contact with CERN at the time. After a short period, CERN offered him an indefinite contract, which he accepted. Since Chuck was a US citizen, this was a very rare exception for a physicist who was not from a Member State. He immediately became involved in experiments at the Intersecting Storage Rings, which recorded its first proton–proton collisions in January 1971. His work on detectors was centred on silicon semiconductors and on multiwire proportional chambers within the group of Georges Charpak. His main topic in physics was the search for fractionally charged particles indicating a signal for free quarks.

Chuck left CERN to work for three ▷

years at the Los Alamos National Laboratory in the US, where he carried out further studies on silicon semiconductor detectors and worked on the development of liquid ionisation chambers. He also received a US patent for his development of laser-beam alignment systems. In 1978 he moved to the Lawrence Berkeley Laboratory (LBL) in California, where he was a professor until his retirement in 1992. LBL was deeply involved in CERN experiments and this allowed Chuck to spend most of his time at CERN, continuing to work on the Split Field Magnet experiment at the ISR. After the closure of the ISR, he participated in CERN's heavy-ion programme in the search for the quark–gluon plasma with the NA36 experiment. He made major contributions to the design and operation of the time projection chamber, including the role of tracking in relativistic heavy-ion experiments.

After his retirement from LBL in 1992, Chuck became a consultant for the ATLAS experiment under a contract with the MPI Munich. He was the first to study the characteristics of single proportional drift tubes, to be produced later on in hundreds of thousands to form the ATLAS Muon Spectrometer, and was our main adviser during the development and testing of the first prototype chambers at the MPI.

Although suffering from heart problems, Chuck stayed active for many years to come. His main remedy against health problems was extensive hiking on the Jura mountains.

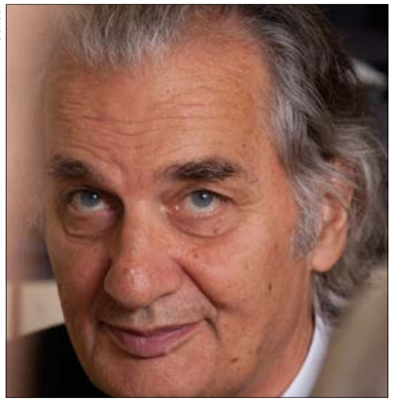
His principal scientific interest during his later years was astronomy and the study of binary stars. He developed methods for their observation, photography and analysis at home with private telescopes, recording real data once a year at the International Amateur Observatory on the Gamsberg in Namibia. Chuck's observations found many acknowledgements due to their high-level professionalism.

Besides the many achievements in his brilliant scientific career, we would like to recall his fine personal qualities. Above all, his greatest quality was perhaps that he was simply a nice person. Our deepest sympathy goes to his wife Ute, their children and families.

● *His friends and colleagues.*

Gerhard Lutz 1939–2017

One of the pioneers of silicon radiation detectors, Gerhard Lutz, passed away in Vienna on 28 April. He will be remembered for numerous inventions that shaped the field of silicon detectors, his deep insight into detector physics and analysis methods, his role as mentor of many young scientists, and his modest and charming personality.



PNSensor

Lutz made numerous seminal contributions in the field of silicon detectors

Gerhard Lutz was born in Klagenfurt, Austria, in 1939. He studied physics at the Technical University of Vienna and obtained his PhD from the University of Hamburg under Willibald Jentschke, the founder of DESY and later a Director-General of CERN. His thesis concerned the coherent bremsstrahlung and pair production on diamond crystals using the DESY synchrotron, and demonstrated the production of GeV photons with a polarisation in excess of 70%. In 1967 he moved to Northeastern University in Boston and contributed to a spectrometer experiment at Brookhaven, which had aimed to follow up spectacular results reported earlier by the "CERN missing mass spectrometer": the splitting of the A_2 resonance and the observation of narrow high-mass resonances. Based on high-quality data and a painstaking analysis, he showed that the CERN results were incorrect.

In 1972, Lutz took a position at MPI-Munich and initiated a precision measurement of the reaction $\pi^- p(\uparrow) \to \pi^- \pi^+ n$. He organised and ran the experiment, wrote the event-reconstruction software and developed the complex mathematical formalism necessary to interpret the results – marking a milestone in the understanding of exclusive hadronic reactions. In the late 1970s the CERN–Munich Group expanded into the ACCMOR collaboration, which pioneered the use of high-precision silicon tracking detectors. Together with Josef Kemmer and Robert Klanner, he developed silicon microstrip detectors using planar technology and built the vertex telescope for the CERN fixed-target experiments NA11 and NA32. The achieved precision of this device (5 μm), its ability to operate reliably in a high-intensity beam and identify charm particles against a huge background of hadronic events, unleashed the success story of silicon detectors. Today, practically all high-energy physics experiments rely on this technology.

Lutz's contributions in the field of silicon detectors are numerous: the understanding of detector instabilities due to surface effects; the development of double-sided silicon-strip detectors; the concept of fully depleted pnCCDs based on the principle of sideway depletion; the realisation of novel concepts for silicon sensors with intrinsic gain; and the invention of the DePFET detector-amplifier structure. His developments found their way into many experiments outside particle physics, in particular in astrophysics and X-ray science, and also industry. Lutz co-founded the Max-Planck-Institut Halbleiterlabor (HLL) semiconductor laboratory in 1992, the research company PNSensor in 2002, and the instrumentation company PNDetector in 2007. Until the very end he contributed to the success of both companies with his sharp mind and inventions, while his guidance, inspiration and ideas have been essential for the success of semiconductor developers in the Munich area.

Those who had the opportunity to work with Gerhard Lutz appreciated his gentle and quiet way, his competence and deep insight. His scientific standards were very high and he detested superficial statements. His unconventional and original ideas inspired many colleagues and students, and his book *Semiconductor Radiation Detectors* has become a classic in the field. Gerhard Lutz's innovative and influential work was honoured by the 1966 Röntgen Award, the 2011 Radiation Instrumentation Outstanding Achievement Award, and the 2017 High Energy Physics Prize of the European Physical Society (see p47).

● *His friends and colleagues.*

Recruitment

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cta
cherenkov telescope array

Position of the Director General for the Cherenkov Telescope Array Observatory

The Cherenkov Telescope Array Observatory (CTAO) is searching for a Director General to lead the organization. The Director General has the overall responsibility for the management of the organization in charge of the construction and future operation of Cherenkov Telescope Array Observatory. The Cherenkov Telescope Array (CTA) is a multinational project to observe extremely high-energy photons from the Universe with greatly improved sensitivity than has been done previously. On the site of the Observatorio del Roque de los Muchachos on La Palma (Canaries, Spain) and at the European Southern Observatory in Chile about 120 telescopes will be installed, in order to measure the Cherenkov radiation produced by the atmospheric particle showers initiated by cosmic photons.

About 200 research institutions from 32 countries are involved in designing and prototyping this large-scale research infrastructure. While the construction of the infrastructure on the sites and all software development is to be managed centrally, most of the telescopes and other scientific components will be delivered as in-kind contributions by interested institutions from all over the world. According to present plans the majority of construction is scheduled to be complete by 2024 within a budget of 400 M€. The observatory is designed for 30 years of operational lifetime. The Cherenkov Telescope Array Observatory headquarters for operation and administration will be set-up in Bologna for the final legal entity. It will be supported by a Science Data Management Centre in Zeuthen near Berlin. Due to the distributed nature of this Research Infrastructure, regular travelling will be needed.
The current transition to the implementation phase is driven by a core of countries acting as the shareholders of the Cherenkov Telescope Array Observatory limited liability company through which the project is presently governed and funded.

We are seeking an internationally renowned science manager with several years of experience in successfully managing large Research Infrastructures or at least large international construction projects. Experience in the relevant experimental areas of CTA would be welcome in addition. He/She will be well experienced in negotiations with international partners and with funding agencies and ministries in particular. Further requirements include: outstanding leadership and communication skills, excellent knowledge of English, competence in contractual and economic affairs.

The Director General shall develop a team spirit that will secure the immediate and long-term success of Cherenkov Telescope Array Observatory. He/she will lead a Management Group that consists during construction of the Administrative Director, the Project Manager and the Director of Science Management. In future a Director of Operation will be also be a member of the Management Group. The Director General shall ensure and develop a suitable and optimal organisation for the transition from the construction to the operational phase of the Cherenkov Telescope Array Observatory. He/she shall also ensure the Cherenkov Telescope Array Observatory's successful transition from the current to the final legal entity. An important responsibility of the Director General will be the management and further development of the distributed CTA-facility with its four sites.
CTAO is an equal opportunity employer and especially encourages applications from women.
Persons with disabilities will be given preference over other applicants with comparable qualifications.

The position is initially limited to a period of five years.

Applications should be submitted by September 1st, 2017 to the Chair and the Vice-Chair of the CTA-Council:

Dr. Paolo Vettolani and Dr. Beatrix Vierkorn-Rudolph
Chair and Vice Chair of the Council of the CTAO gGmbH
Saupfercheckweg 1
D-69117 Heidelberg, Germany

or via e-mail:

vettolani@inaf.it and **Vierkorn-Rudolph@t-online.de**

For further information, please contact **Dr. Vierkorn-Rudolph** (**Vierkorn-Rudolph@t-online.de**).

FAIR
Facility for Antiproton and Ion Research

GSI
Helmholtzzentrum für Schwerionenforschung GmbH

GSI Helmholtzzentrum für Schwerionenforschung operates a unique large-scale accelerator for ions. Researchers from around the world use this facility for experiments which help them make fascinating discoveries concerning the building blocks of matter and the evolution of the universe. In addition, they continually develop novel applications in medicine and technology. In the coming years the new international accelerator facility FAIR (**F**acility for **A**ntiproton and **I**on **R**esearch), one of the largest research projects worldwide, will be built at GSI.

We are looking for a

Head of Electronics for Experiment (m/f)

Reference No: 6220-17.48

Your duties:

You will lead the department for electronics for experiment of GSI GmbH with in total 30 employees plus students. The department conducts a broad portfolio spanning over the full range of electronics activities like analog and digital electronics, system design, ASIC development, embedded software (e.g. FPGA), data acquisition (DAQ) and analysis, control systems as well as layout, assembly and rapid prototyping. You work closely with the international experiment collaborations at GSI and FAIR in a project oriented structure. You will strategically develop the department to support existing and future instrumentation for experiments at GSI and FAIR.

Your Profile

We are looking for a person with the following qualification:

- University degree in Electronics or Physics, preferably PhD
- Outstanding expertise in modern front-end electronics for nuclear and particle physics experiments
- Several years of work experience in a supervising position in electronics; ideally acquired in a comparable organization
- Professional experience with stringent real-time requirements / low-latency systems / low-noise systems
- Excellent written and oral English language skills. Good German language skills will be an asset
- Goal-oriented and analytical mindset, strong skills in people management and resource handling.

Please provide us with a short summary on your vision on the future in experiment electronics in the framework of GSI and FAIR.

We are offering an interesting and varied professional activity in an international reputable research institute. We offer an indefinite contract. Salary is equivalent to that for public employees as specified in the collective agreement for public employees (TVöD Bund).

Further information about FAIR and GSI is available at www.gsi.de and www.fair-center.eu.

GSI supports the vocational development of women. Therefore, women are especially encouraged to apply for the position.

Severely disabled applicants will be given preference to other applicants with equal qualifications.

Please send your complete application including the usual documents, your salary expectation and the above **Reference No.** by **July 31st 2017** to:

GSI Helmholtzzentrum für Schwerionenforschung GmbH
Abteilung Personal
Planckstraße 1
64291 Darmstadt
or by E-Mail to: **bewerbung@gsi.de**

Northern Illinois University

OPPORTUNITY FOR TENURE-TRACK ASSOCIATE and ASSISTANT PROFESSORSHIP APPOINTMENTS IN ACCELERATOR PHYSICS (JOINTLY WITH FERMILAB)

The Physics Department of Northern Illinois University is home to world-class faculty in accelerator, detector and particle physics. In a joint initiative with Fermi National Accelerator Laboratory (Fermilab), it has established a Cluster of Research Excellence in accelerator science and beam physics since 2014. Faculty members have national and international research and educational collaborations with Fermilab, Argonne National Laboratory (ANL), SLAC, CERN, DESY and USPAS/ CERN Accelerator Schools. Funded by the National Science Foundation, the Department of Energy and other institutional and national agencies, the Accelerator and Beam Physics faculty members in the cluster work at the theoretical and experimental frontiers, with full access to special purpose laboratories and advanced accelerator test facilities at NIU and Fermilab (e.g. NIU High Brightness Electron Source laboratory in IARC and Fermilab FAST/IOTA testbed). The research cluster aims at enabling "discovery-class" science driven by charged particle beams and associated advanced techniques/ technologies of lasers, bright electron and ion sources, nano-material structures, superconductivity, microwave cavity electrodynamics, nonlinear dynamics, electrodynamic and optical control of intense charged particle, atomic and molecular beams. The R&D is directed towards developments in particle physics and related disciplines of cosmology, material and life sciences and their applications to societal grand challenges of energy, environment, health and security.

Working seamlessly with the outstanding accelerator and technology research staff at Fermilab and Northern Illinois Centre for Accelerator and Detector Development (NICADD), unique collaborative research opportunities exist to contribute to large scale national and international accelerator activities such as the PIP-II at Fermilab for the development of the long-baseline neutrino facility in support of the international DUNE experiment, TeV-scale collider developments world-wide including the LHC and its upgrade and the FCC at CERN, "precision" experiments e.g. "g-2", "Mu-2-e" etc. at Fermilab, anti-matter related experiments at CERN, as well as cutting edge innovative research in laboratory –scale experiments to investigate the "dark" sector of the vacuum.

The cluster seeks appointment of two tenure-track faculty members in accelerator physics, jointly with Fermilab, at Associate/Assistant Professor levels as soon as possible. Aspiring candidates, with a PhD degree in Physics or equivalent and relevant post-doctoral experience beyond, should contact Professor Swapan Chattopadhyay, President's Professor and Director of Accelerator Reserarch, NIU (schaterji@niu.edu) and Distinguisehd Scientist, Director's Senior Leadership Team, Fermilab (swapan@fnal.gov) for further details and send early expressions of interest and professional background information in advance before August 15, 2017. Candidates from historically underrepresented communities are especially encouraged to apply. A detailed job posting with specific directions for applications will be announced online and selected journals soon.

Chair for Experimental nuclear and particle physics at Vilnius University, Lithuania

Vilnius University is seeking an excellent scientist to fill a leading position in the Faculty of Physics. The successful candidate is expected to build a research team to carry out studies in the field of experimental particle physics, and establish a strong connection to CERN. She/he is also expected to work in close collaboration with other research groups at Vilnius University, with the aim to increase the level of cooperation between Lithuania and other international scientific and academic institutions, and with particular attention to Lithuania-CERN cooperation.

Vilnius University has joined CERN RD collaborations in 2002 and the CMS experiment in 2007. Previous participation in one of the major experiments at the Large Hadron Collider at CERN (ALICE, ATLAS, CMS or LHCb) will be considered an advantage.

Vilnius University is the oldest and most comprehensive university in Lithuania. According to "QS World University Rankings 2016-2017", it is among top 500 universities in the world. The academic staff consists of 1350 employees (250 of them are professors) and around 20,000 students, including 3,600 graduate and 900 doctoral students.

The research laboratories of the Faculty of Physics have premises in the National Centre of Physical and Technological Sciences in Sunrise Valley ("Saulėtekio") since 2016. The Valley is the largest and most advanced base for physical, chemical and life sciences and for technology in Lithuania and the Baltic states. The lecture rooms and the educational laboratories at the Faculty of Physics, the largest center of physics studies in Lithuania, are situated nearby.

A Chair position is equivalent to a full professor position. The incumbent is expected to fulfill the requirements corresponding to the recommended European competences for a leading (R4) or, at least, an established (R3) researcher.

Candidates must have been trained at international particle physics laboratories and leading national collaborating institutions, with expertise in modern experimental particle physics. They must demonstrate a proven record in securing significant research funding/budgets/resources and experience in managing and leading research projects.

Applications are invited from candidates of any nationality and gender. Citizens of non-EU countries will need to fulfil the requirements for obtaining a work permit in Lithuania. The successful candidate must take residence in Vilnius.

Chair's mission: ● Coordinate Lithuania's research activities in theoretical and experimental high energy physics, and in materials and computer sciences and medical applications relevant to CERN research fields; ● facilitate the involvement of researchers at Vilnius University into the programmes and experiments conducted at CERN; ● organize teaching and training of students and young researchers in particle physics, particle detector techniques, data processing and related fields; ● raise the public awareness for fundamental physics such as the current understanding of the Universe and its origin in a form that is suitable for a broad audience.

Full details of the Chair's duties will be provided upon request.

The successful candidate will be entitled to: ● a separate office; ● premises to establish her/his own laboratory, if the existing infrastructure does not match the needs, within the limits of the Centre's financial possibilities; ● Salary Range: negotiable and depending on experience.

The applications should be sent to VU Directorate of Personnel zis@cr.vu.lt **The deadline: 10 September, 2017.**

A cover letter should include a request to participate in the contest and should be addressed to the Rector of Vilnius University.

Also, a description of academic activities together with a list of scientific publications, curriculum vitae, an outline of the research plan and any other additional documents allowing to objectively evaluate the qualifications of the applicant.

The letters of support from senior scientists with an established track record in high-energy nuclear and particle physics (min 3, max 6) should be sent directly to Vilnius university (zis@cr.vu.lt).

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eli beamlines

Institute of Physics ASCR, v. v. i., Na Slovance 2, 182 21 Praha 8
info@eli-beams.eu | www.eli-beams.eu

The ELI (Extreme Light Infrastructure) Project is an integral part of the European plan to build the next generation of large user and research facilities. ELI-Beamlines, as a cutting edge facility, is currently being constructed in Prague, Czech Republic. ELI will provide for both fundamental and applied research sources (beamlines) of energetic photons and charged particles accelerated or generated in laser-driven plasma under extremely high intensities of electromagnetic fields.

The theory and simulation group wants to reinforce their activities in the field of macroscopic laser-plasma interaction and its simulation. This is of importance to pre-pulse physics for high- power laser-matter interaction as well as for inertial confinement fusion.

The work is supposed to prepare and accompany experiments planned at international high- intensity laser facilities and help to define the research program for ELI-Beamlines.

In our team we therefore have the following position available:

Junior scientist for macroscopic laser-plasma interaction

Job description:

- Macroscopic simulations of laser-plasma interaction are essential for a detailed understanding of the underlying physics on macroscopic spatial scales and temporal scales
- This requires the development of accurate models for transport processes of particles and photons, correct laser absorption models and accounting for possible backscattering.
- The work will require to develop these new models in collaboration with other groups locally and internationally and to incorporate them in numerical simulation tools.

Requirements:

- PhD in theory/simulation of hot plasmas
- Experience with simulation work and code development
- Good analytical skills
- Very good working knowledge of English
- Previous experience in laser-plasma interaction studies would be a plus
- Experience with one or more programming languages (C, C++, Fortran)

Job conditions:

- The opportunity to participate in this unique scientific project
- Career growth, professional education
- Competitive and motivating salary
- 5 weeks of holiday and other employee benefits

Applications, containing CV, cover letter, contacts of references, and any other material the candidate considers relevant, should be sent to Mrs. Jana Ženíšková, HR specialist (jana.zeniskova@eli-beams.eu, +420 - 601560322). Please include the following text in your cover letter, to allow us to process your personal details:

I agree that, according to the decree 101/2000 coll. (Czech Republic), my personal details sent to FZU AV CR, v.v.i., Na Slovance 2, 18221 Praha 8, Czech Republic can be used for the purpose of obtaining employment and management of database of employment candidates. This permission is given for the period of one year and can be at any time withdrawn by giving a notice in writing.

IFIN-HH

Senior and Junior Researchers, Postdoctoral research assistants, PhD students, Engineers, Physicists and Technicians at

Extreme Light Infrastructure – Nuclear Physics (ELI-NP)

eli nuclear physics

Extreme Light Infrastructure – Nuclear Physics (ELI–NP) will be the most advanced research infrastructure in the world focusing on photonuclear physics studies and applications, implemented by the the Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH) in Bucharest – Magurele, Romania.

ELI-NP is a complex facility which will host two state-of-the-art equipment of high performances:

- A very High Power Laser System with two 10 PW arms based on Optical Parametric Chirped Pulse Amplification, able to reach intensities of 10^{23} W/cm^2 and electrical fields of 10^{15} V/m;
- A very intense, brilliant Gamma Beam System, ~ 0.1 % bandwidth, with E γ up to 19.5 MeV, which is obtained by incoherent Compton back scattering of a laser light off a very intense electron beam (E_e up to 720 MeV) produced by a warm LINAC.

IFIN-HH – ELI-NP is organizing competitions for filling the following positions:

Senior and Junior Researchers, Postdoctoral research assistants, PhD students, Engineers/ Physicists (laser engineers for 10PW lasers, particle accelerators, electrical, electronics, control systems, detectors, DAQ, optics) and Technicians (vacuum systems-laser operations, vacuum R&D, detectors and spectroscopy, DAQ and control systems)

The jobs description, the Candidate's profiles and the Rules of Procedures of Selection can be found at http://www.eli-np.ro/jobs.php.

The applications shall be accompanied by the documents required in the Rules and Procedures of Selection for these positions

The applications shall be sent to the Human Resources Department at human.resources@eli-np.ro.

TeraView

Terahertz Physics: Electromagnetic Modelling, High Frequency Devices and Imaging Applications

TeraView Ltd is the world's first and leading provider of Terahertz solutions to companies in a variety of industries. TeraView was created in 2001 from pioneering work carried out between the University of Cambridge and the Toshiba Corporation with a vision is to establish Terahertz as the premier imaging tool for the 21st century, used to improve the products and process of TeraView's customers.

The Company is currently recruiting several PhD level candidates to work on the following topics:

1. Extension of existing electromagnetic simulations of the propagation of Terahertz pulses through advanced integrated circuits and devices developed by the semiconductor industry. This work will involve investigating specific customer designs for integrated circuits, and liaising with the customers to improve the design and processing of these devices.
2. Development of a new generation of Terahertz emitters and detectors for high frequency imaging and spectroscopic applications, with the goal to improve the throughput, resolution and sensitivity of Terahertz sensing.
3. Development of new and existing applications of Terahertz imaging and spectroscopy in close collaboration with customers.

The successful applicants will have demonstrated initiative, software/algorithmic development skills and a good understanding of the physics of high frequency devices. The ability to present well at conferences and represent the Company is paramount.

TeraView offers an excellent package of salary and employee benefits. We are an equal opportunities employer and pride ourselves on our diverse workforce.

We are an equal opportunities employer and pride ourselves on our diverse workforce.

For further information and background on the company, please visit our website www.teraview.com

To apply for these positions, your CV, with full career and publication details, should be sent to Mr John Westgate, John.Westgate@teraview.com

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Bookshelf

Compiled by Virginia Greco, CERN

Trick or Truth? The Mysterious Connection Between Physics and Mathematics

By Anthony Aguirre, Brendan Foster, Zeeya Merali (eds)
Springer

One of the most intriguing works in the philosophy of science is Wigner's 1960 paper titled "The Unreasonable Effectiveness of Mathematics in the Natural Sciences". Indeed the fact that so many natural laws can be formulated in this language, not to mention that some of these represent the most precise knowledge we have about our world, is a stunning mystery.

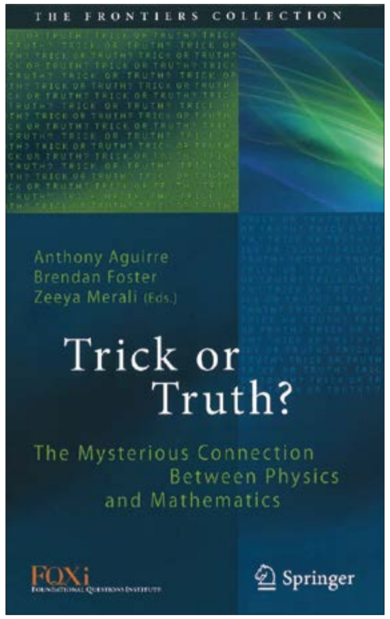
A related question is whether mathematics, which has largely developed overlapping or in parallel with physics, is constructed by the human mind or "discovered". This question is worth asking again today, when modern theories of fundamental physics and contemporary mathematics have reached levels of abstraction that are unimaginable from the perspective of just 100 years ago.

This book is a collection of essays discussing the connection between physics and mathematics. They are written by the winners of the 2015 Foundational Questions Institute contest, which invited contributors – from professional researchers to members of the public – to propose an essay on the topic.

Since it appears primarily as a subject of the philosophy of science rather than of science itself, it is not a surprise that there are conflicting viewpoints that sometimes reach opposite conclusions.

A significant point of view is that the claimed effectiveness of mathematics is actually not that surprising. This is because we process information and generate knowledge about our world in an inadvertently biased way, namely as a result of the evolution of our mind in a specific physical world. For example, concepts of elementary geometry (such as straight lines, parabolas, etc) and the mechanics of classical physics are deeply imprinted in the human brain as evolutionary bias. In a fuzzy, chaotic world, such naive mathematical notions might not have developed, as they wouldn't represent a good approximation to that world. In fact, in a drastically unstructured world it would have been less likely that life had evolved in the first place, so it may not seem such a surprise that we find ourselves in a world largely governed by relatively simple geometrical structures.

What remains miraculous, on the other hand, is the effectiveness of



mathematics in the microscopic realm of quantum mechanics: it is not obvious how the mathematical notions on which it is based could be explained in terms of evolutionary bias. Actually, much of the progress of fundamental physics during the last 100 years or so crucially depended on abandoning the intuition of everyday common sense, in favour of abstract mathematical principles.

Another aspect is selection bias, in that failures of the mathematical description of certain phenomena tend simply to be ignored. A prime example is human consciousness – undoubtedly a real-world phenomenon – for which it is not at all clear whether its structure can ever be mapped to mathematical concepts in a meaningful way. A quite common reductionist point of view typical of particle physicists is that, since the brain is essentially chemistry (thus physics), a mathematical underpinning is automatic. But it may be that the way such complex phenomena emerge completely obfuscates the connection to the underlying, mathematically clean microscopic physics, rendering the latter useless for any practical purpose in this regard.

This raises the issue of the structure of knowledge per se, and some essays in this book argue that it may not necessarily be hierarchical but rather scale invariant with some, or many, distinguished nodes. One may think of these as local attractors to which "arrows of deeper explanation" point. It may be that only locally near such attractors does knowledge appear hierarchical, so that, for example, our mathematical description of fundamental physics is meaningful only near one particular such node. There might be other local attractors that are decoupled from our mathematical modelling, with no obvious chains of explanation linking them.

On a different tack, a vehemently dissimilar and extreme point of view is taken by adepts of Tegmark's mathematical universe hypothesis, which has been directly addressed by various authors. This posits that there is actually no difference between mathematics and the physical world, so the role of mathematics in our physical world appears as a tautology.

Surveying all the thoughts in this collection of essays would be beyond the scope of this review. Suffice it to say that the book should be of great interest to anybody pondering the meaning of physical theories, although it appears more useful for scientists rather than for the general public. It is not an easy read, but the reader is rewarded with a great deal of food for thought.

● *Wolfgang Lerche, CERN.*

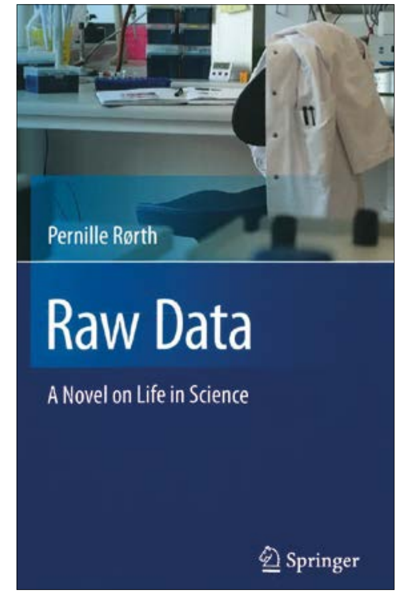
Raw Data: A Novel on Life in Science

By Pernille Rørth
Springer

Raw Data is a scientific novel that explores the moral dilemmas surrounding the accidental discovery of a case of scientific misconduct within a top US biomedical institute.

The choice of subject is interesting and unusual. Scientific misconduct is not an unprecedented topic for scientific novels, but the focus is usually on spectacular frauds that clearly violate the ethos of the scientific community. This story depicts a more nuanced situation. Readers may even find themselves understanding, if not condoning, the conscious decision of one of the co-protagonists to cheat.

This character chooses to "cut a corner" out of fear of being scooped, to satisfy an unreasonably picky reviewer who had requested an additional control experiment that she deems irrelevant. The stakes for her career are huge because she is competing with other groups on the same research line, and publishing second would cost her a great deal academically. When a co-worker accidentally finds hints of her



fabrication and immediately alerts the laboratory's principal investigator, both find themselves in a bitter no-win situation. "Doing the right thing" has a significant cost, but any other option potentially entails far worse consequences for their careers and their reputations.

Along the way, the author illustrates vividly how people in research think, feel, work and live. Work–life balance in science, especially for young female researchers, is a secondary theme of the book. Overall, the portrait of academia is not a flattering one, but definitely faithful. As someone who works in high-energy physics, I learnt about day-by-day practices in the biomedical sector and how it differs from mine. Although the author focuses on her own area of the scientific environment, some descriptions of "postdoc life" are quite general.

This relatively short novel is followed by a long Q&A section with the author, a former biomedical researcher who left the field after some considerable career achievements. There she makes her opinions explicit about several of the topics, including the "publish or perish" attitude, work–life balance, scientific integrity, and what she perceives as systemic dangers for the academic research world.

Although the author clearly made an effort to simplify the science to the minimum needed to understand the plot (and as a reader with no understanding of microbiology I found her effort successful), I am not sure that a reader with no previous interest in science would be hooked by the story. The book is well written, but the plot has a slow pace and, while Springer deserves credit for publishing it, the text contains many typographical errors.

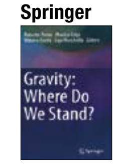
Overall, I recommend the book to other scientists, regardless of their specialisation, and to the scientifically educated public who may appreciate this insider view of contemporary research life.

● *Andrea Giammanco, UCLouvain, Louvain-la-Neuve, Belgium.*

Books received

Gravity: Where Do We Stand?

By R Peron, M Colpi, V Gorini and U Moschella (eds)
Springer



This book, a collection of expert contributions, provides an overview of the current knowledge in gravitational physics, including theoretical and experimental aspects.

After a pedagogical introduction to gravitational theories, several chapters explore gravitational phenomena in the realm of so-called weak-field conditions: the Earth (specifically, the laboratory environment) and the solar system.

The second part of the book is devoted to gravity in an astrophysical context, which is an important test-bed for general relativity. A chapter is dedicated to gravitational waves, the recent discovery of which is an impressive experimental result in this field. The importance of studying radio pulsars is also highlighted.

A section on research frontiers in gravitational physics follows. This explores the many open issues, especially related to astrophysical and cosmological problems, and the way that possible solutions impact the quest for a quantum theory of gravity and a unified theory of the forces.

The book's origins lie in the 2009 edition of a school organised by the Italian Society of Relativity and Gravitation. As such, it is aimed at graduate students, but could also appeal to researchers working in the field.

Principles of Magnetostatics

By Richard C Fernow
Cambridge University Press

This book aims to provide a self-contained and concise treatment of the main subjects in magnetostatics, which describes the forces and fields resulting from the steady flow of electrical currents.

The first three chapters briefly present the basics, including the theory of magnetic fields from conductors in free space and from magnetic materials, as well as the general solutions to the Laplace equation and boundary value problems. Then the author moves on to discuss transverse fields in two dimensions. In particular, he covers fields produced by line currents, current sheets and current blocks, and the application of complex variable methods. He also treats transverse field magnets where the shape of the field is determined by the shape of the iron surface and the conductors are used to excite the field in the iron.

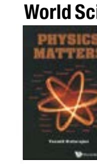
The following chapters are dedicated to other field configurations, such as axial field arrangements and periodic magnetic arrangements. The properties of permanent magnets and multiple fields produced by assemblies of them are also discussed.

Finally, the author deals with phenomena where there are slow variations in current or magnetic flux. Since only a restricted group of magnetostatic problems have analytic solutions, in the last chapter numerical techniques for calculating magnetic fields are provided, accompanied by many examples taken from accelerator and beam physics.

Aimed at undergraduates in physics and electrical engineering, the book includes not only basic explanations but also many references for further study.

Physics Matters

By Vasant Natarajan
World Scientific



This book is a collection of essays on various physics topics, which the author aims at presenting in a manner that is accessible to non-experts and, specifically, to non-physics science and arts students at the undergraduate level. The author is motivated by the conviction that understanding fundamental concepts of other subjects facilitates out-of-the-box thinking, which can result in making original contributions to one's chosen field.

The selection of topics is very personal: some basic-physics concepts, such as standards for units and oscillation theory, are placed next to discussions about general relativity and the famous twin paradox. The author uses an informal style and has particular interest in dispelling some myths about science.

The final chapters cover topics from his area of research, atomic and optical physics, focusing on the Nobel Prizes assigned in the last two decades to scientists in these fields.

Even though the use of equations is kept to a minimum, some mathematics and physics background is required of the reader.

CERN Courier Archive: 1974

A look back to CERN Courier vol. 14, July/August 1974, compiled by Peggie Rimmer

CERN NEWS

52nd Session of CERN Council

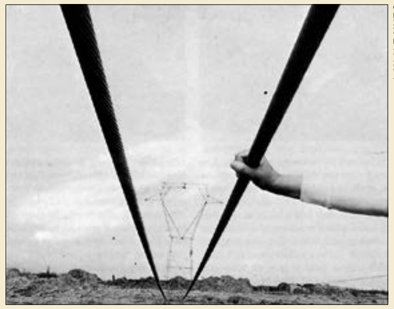
At the 52nd CERN Council Session in June the Directors General presented reports from the two CERN Laboratories.

W K Jentschke mentioned further evidence for neutral currents in neutrino experiments with the Gargamelle heavy liquid bubble chamber, evidence for the unification of the weak and electromagnetic interactions. Another example of neutrino-electron scattering has been seen and over two hundred events on nucleons are now confirmed. In addition, an experiment with a proton beam into the chamber has checked that the estimate of the background, which could result in other events being confused with neutral current events, is correct.

Steady progress in building the 400 GeV super proton synchrotron (SPS) in Lab II was reported by J B Adams. He emphasised the work on the machine tunnel. At the time of the Council Session, the "mole" had bored its way around 90% of the 7 km circumference of the machine, maintaining an accuracy of better than 5 cm compared to its planned position.

Everything remains on schedule for commissioning the accelerator in the second half of 1976.

● Compiled from texts on pp247–249.



CERN 24.4.74

Major services to the Laboratory II site are nearing completion: installation of the 380 kV electrical power lines is well advanced over the 40 km linking the Laboratory to the European grid at Génissiat.

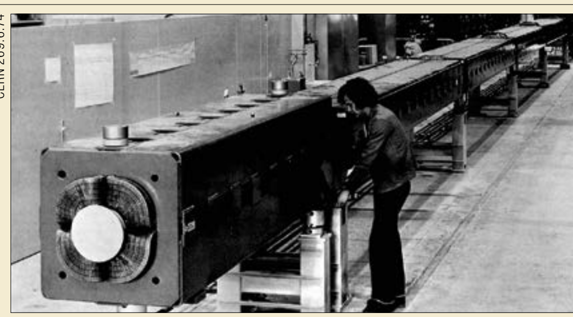
CERN 182.5.74

Two 5000 m³ reservoirs are to hold the site water supply brought from Lac Léman. One of them has already been filled and is distributing water to part of the site.

Completion of the SPS tunnel

On 12 March 1973 the Robbins boring machine was ready, 50 metres underground, to start piercing the SPS tunnel, 4.8 metres in diameter, through the layer of molasse – a ring 6900 metres in circumference. On 31 July 1974 the "mole" finished the job, completing a major stage in the construction of the 400 GeV accelerator. The machine worked with commendable efficiency, boring at an average rate of about 21 metres per day – faster than originally foreseen. Apart from rest days, there were four breaks, totalling eleven weeks out of the sixteen and a half months of operation.

● Compiled from texts on p248, pp251–252.



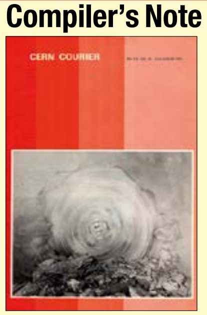
CERN 269.6.74

To test assembly and alignment procedures for the imminent installation of components in the SPS tunnel, a 30 metre stretch of machine comprising four bending magnets flanked by two quadrupoles has been linked up in the Lab II large assembly hall.

CERN 236.7.74

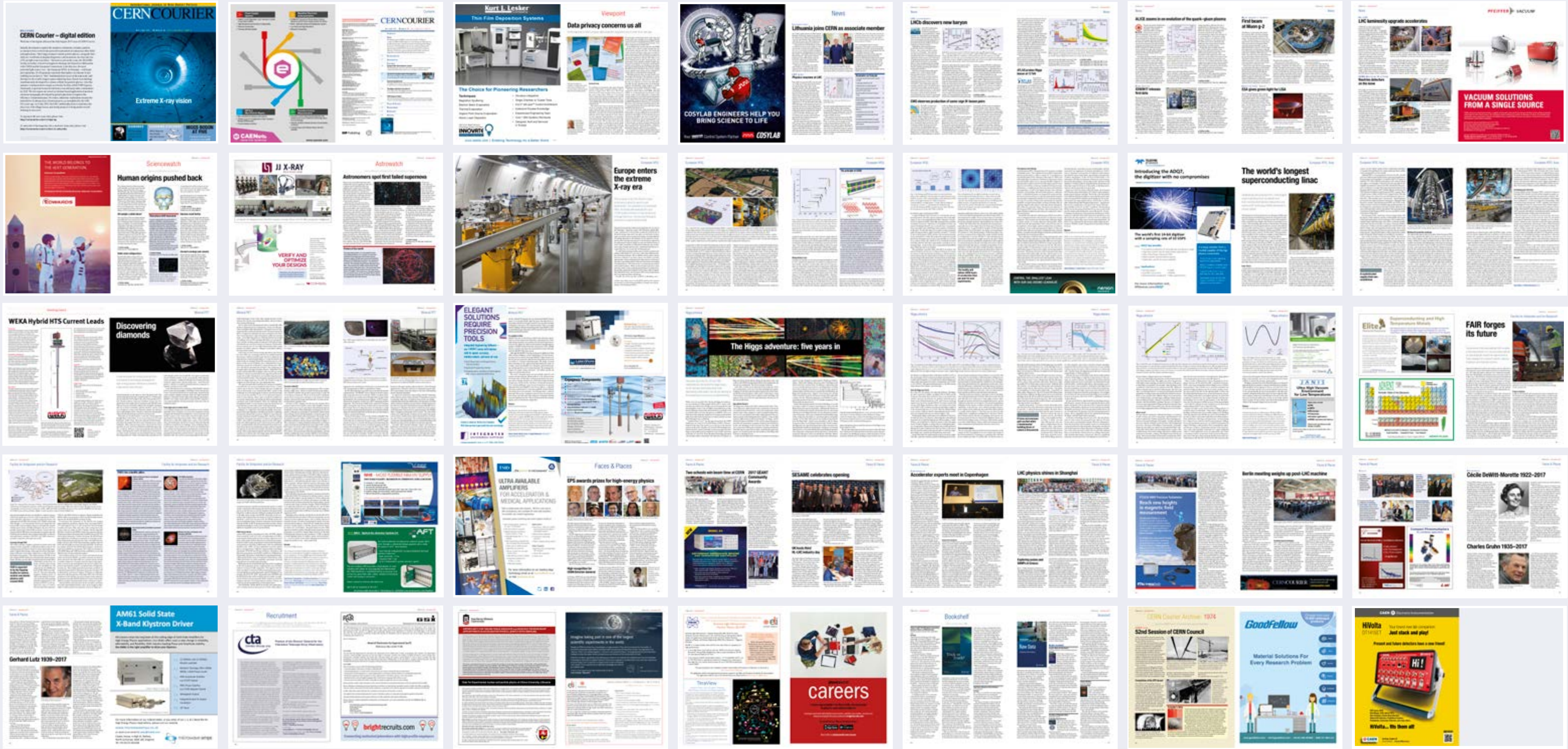
At precisely 10.32 a.m. on 31 July, the "mole" reached the end of its 7 km journey. A group of VIPs and journalists were present at the final breakthrough.

Compiler's Note



The SPS came into operation in May 1976. Designed to accelerate protons, in 1981 it became the world's first proton–antiproton collider, enabling the discovery of the weak-interaction bosons, W and Z. This consolidated the unified electroweak theory and earned the 1984 Nobel Prize for Carlo Rubbia and Simon van der Meer. Today this venerable workhorse is again accelerating protons, as a go-between in CERN's accelerator complex, taking 25 GeV beams from the PS up to 450 GeV for injection into the LHC.

Underpinning new particles and coveted prizes is the laboratory's life-support system – electricity and water. Consumption depends on whether the machines are running or shut down for maintenance. Typically, the LHC operates between May and December, being switched off during the winter as an economy measure. In such a year, CERN consumes around 1.3 TWh of power, provided via a French substation in Prévessin, and about 4 Mm³ of water, most of it pumped out of Lake Geneva at Le Vengeron – enough water to run the iconic Jet d'Eau for about three months.



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