WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the March 2017 issue of *CERN Courier*.

High-energy physics relies increasingly on international collaboration to plan, build and operate large experimental facilities. The Deep Underground Neutrino Experiment (DUNE) is a case in point. Due to be operational in the US by the early 2020s, driven by a rapidly growing international collaboration, DUNE's vast liquid-argon detectors are being prototyped at CERN as part of the laboratory's recently established Neutrino Platform. Another project that relies on strong US–European collaboration is CERN's High-Luminosity LHC (HL-LHC), which will boost the collision rate and thus discovery potential of the LHC by a factor 10. Building on long-standing partnerships, US laboratories are working closely with CERN to develop the advanced niobium-tin magnets and other superconducting technologies for the HL-LHC, for which civil-engineering work is now ready to begin. Meanwhile, astroparticle physicists from 11 countries are working on the design of the DARWIN observatory, which promises to be the ultimate WIMP dark-matter detector. Perhaps the most extraordinary example of scientific collaboration in recent times is the SESAME light source in Jordan, which has just circulated its first electrons and whose founding members include Iran, Israel and the Palestinian Authority. Finally, we report on a highly interdisciplinary collaboration between particle physicists, medical experts and industry that aims to make radiotherapy more widely available in low- and middle-income countries.

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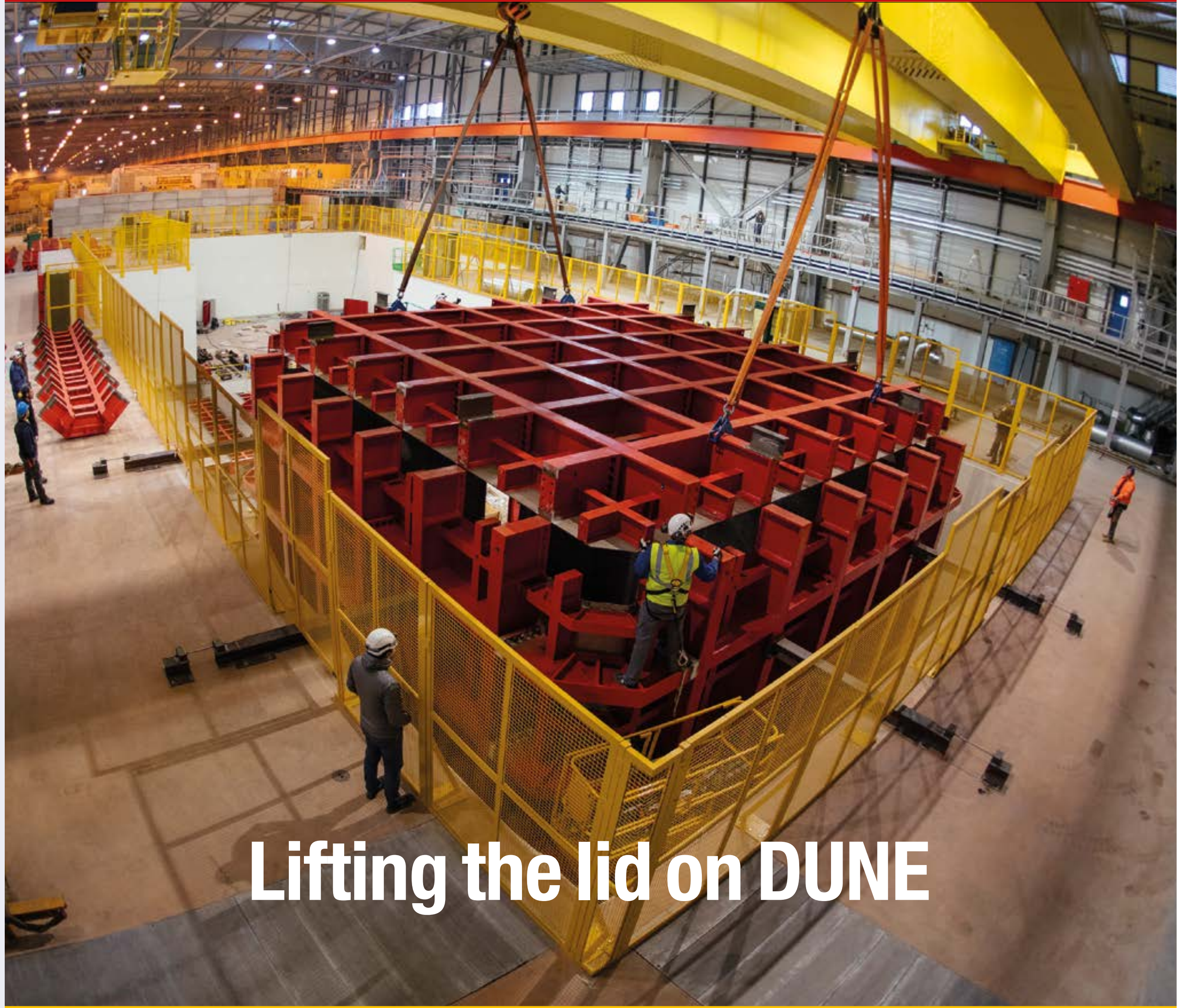

Lifting the lid on DUNE

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

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On the cover: The roof structure of protoDUNE being lowered into place at CERN in December. (Image credit: M Brice/CERN.)

Viewpoint

Reaching out in the era of big science

Now a formal collaboration, IPPOG provides a new force for global particle-physics outreach.

S Bennett/CERN

CERN director for international relations, Charlotte Warakaulle, signs the memorandum of understanding with IPPOG chairperson Hans Peter Beck on 19 December, allowing the IPPOG collaboration to officially enter into force.

By Hans Peter Beck

Establishing and maintaining a strong link between science and society is vital, and is something that has long been recognised by CERN. Writing in 1972, former Director-General Victor Weisskopf put it well when he argued that a concerted effort towards the presentation and popularisation of science would "provide a potent antidote to overspecialisation, bring out clearly what is significant in current research, and make science a more integral part of the culture of today".

Forty-five years later, as we enter the so-called "post-factual world" emerging from political ideologies in a growing number of modern democracies, it is more important than ever for science and society to maintain an open and transparent dialogue. It has also become evident that the tools and methods currently used to support such a dialogue have not been as successful as we would have hoped. Indeed, many excellent outreach activities at research centres, universities and museums often attract only those people who are already interested and appreciative of the basic and fundamental relevance of science.

Without compromising established methods, we must explore new paths to engage citizens – especially the young. Reaching out to high-school students and their teachers to convey the methods and tools used in fundamental science is a strong investment in the future. While only a fraction of young students will become scientists, and fewer still will become particle physicists, all will become ambassadors for the scientific method and evidence-based decision-making. Developing a dialogue with those who have left school early raises important challenges of its own, and requires that scientists take courageous steps. Partnering with artists, musicians and celebrities, for instance, has enormous potential to get science into the spotlight. But it involves a delicate balance between raising curiosity and descending into trivialities.

The International Particle Physics Outreach Group (IPPOG) is making a concerted and systematic effort to present and popularise particle physics across all audiences and age groups. Established 20 years ago following the recommendations of former CERN Director-General Christopher Llewellyn Smith, IPPOG has evolved from a European to a global network that involves countries, laboratories and scientific collaborations active in particle-physics research. It is best known for its International Masterclasses (IMC) programme, which evolved in the mid-1990s from national outreach efforts in the days of the LEP collider and has gone from strength to strength. Since 2005, the programme has offered high-school students the opportunity to become physicists for a day by performing a tailor-made physics analysis involving real LHC data (*CERN Courier* June 2014 p37). In terms of numbers, last year's edition of the IMC included 213 institutions in 46 countries and around 13,000 students took part.

Particle physics has become a truly global activity, with experimental collaborations such as those of the LHC experiments featuring thousands of researchers from all over the world. With this trend, IPPOG is evolving further to cover more countries, laboratories and experiments spanning all aspects of collider and non-collider research, including astroparticle physics and accelerator and detector technology. This expanding remit demands that IPPOG adopts a more formal structure to guarantee the quality and sustainability of its work.

Following the model of collaboration in experimental particle physics, on 19 December IPPOG became a formal scientific collaboration based on a memorandum of understanding. A total of 13 countries have now signed as members, with several candidate members expected to join soon, and each is required to contribute a membership fee weighted by its GDP and the size of its particle-physics community. Laboratories and even individual scientific collaborations are also part of IPPOG, where they contribute to the expert knowledge and skills required to inspire young thinkers.

The new collaboration status of IPPOG, and CERN's formal membership, demonstrates a clear commitment to sustainable science outreach. With further countries and organisations expected to join soon, and others invited to get involved, the worldwide particle-physics community has a strong partner at hand when reaching out to wider society in diverse ways that are adapted for every target audience.

Hans Peter Beck is chairperson of IPPOG, member of the ATLAS experiment and a reader at the University of Bern. (Image credit: C Marcelloni.)

News

ANTIMATTER

BASE boosts precision of antiproton magnetic moment

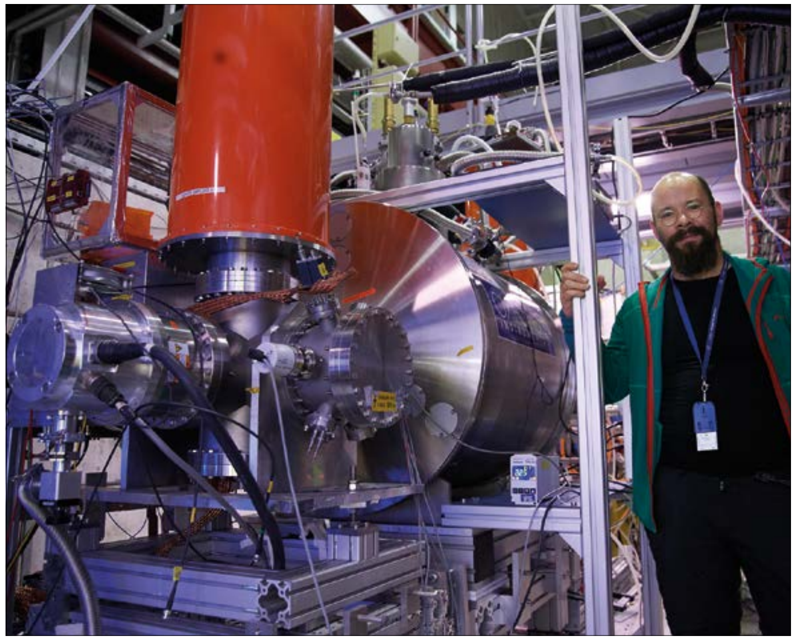
The Baryon Antibaryon Symmetry Experiment (BASE) collaboration at CERN has made the most precise direct measurement of the magnetic moment of the antiproton, allowing a fundamental comparison between matter and antimatter.

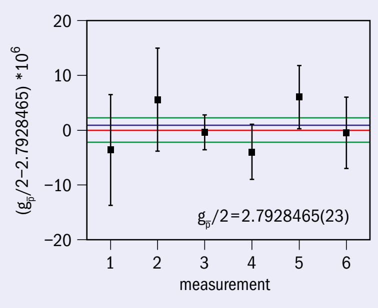
The BASE measurement shows that the magnetic g-factors (which relate the magnetic moment of a particle to the nuclear magneton) of the proton and antiproton are identical within the experimental uncertainty of 0.8 parts per million: 2.7928465(23) for the antiproton, compared to 2.792847350(9) for the proton. The result improves the precision of the previous best measurement by the ATRAP collaboration in 2013, also at CERN, by a factor of six.

Comparisons of the magnetic moments of the proton and antiproton at this level of precision provide a powerful test of CPT invariance. Were even slight differences to be found, it would point to physics beyond the Standard Model. It could imply, for example, the existence of a new vector boson that couples only to antimatter, which could have a direct effect on the lifetime of baryons. Such effects more generally could also shed light on the mystery of the missing antimatter observed on cosmological scales.

BASE uses antiprotons from CERN's Antiproton Decelerator (AD), which serves several other experiments making rapid progress in precision antimatter measurements (*CERN Courier* December 2016 p16). By trapping the particles in electromagnetic containers called Penning traps and cooling them to temperatures below 1 K, the BASE team can measure the cyclotron and Larmor frequencies of single trapped antiprotons. By measuring the ratio of these two frequencies the magnetic moment of the antiproton is obtained in units of the nuclear magneton.

Similar techniques have been successfully applied in the past to electrons and positrons. However, antiprotons present a much bigger challenge because their magnetic moments are considerably weaker, requiring BASE to design Penning traps with about 2000 times higher sensitivity with respect to magnetic moments. BASE now plans to measure the antiproton magnetic moment using a new double-Penning trap technique, which should enable a precision at the level of a few parts per billion in the future.


M Brice/CERN

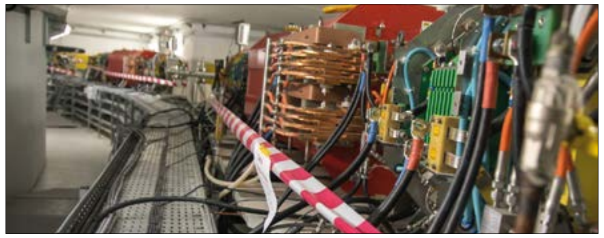


(Top) BASE spokesperson Stefan Ulmer standing next to the experiment's trapping apparatus at CERN's Antiproton Decelerator facility. (Above) Six measurements of the antiproton g-factor were made (average shown in red, with 95% confidence levels in green), to be compared with the accepted value for the proton (blue).

● **Further reading**

H Nagahama *et al.* 2017 *Nature Communications* **8** 14084.
ATRAP Collaboration 2013 *Phys. Rev. Lett.* **110** 130801.

Sommaire en français



N Caraban/CERN

SESAME was established under the auspices of UNESCO before becoming a fully independent intergovernmental organisation in its own right in 2004.

LIGHT SOURCES

SESAME sees first beam

Late in the evening of 12 January, a beam of electrons circulated for the first time in the SESAME light source in Jordan. Following the first single turn, the next steps will be to achieve multi-turns, store and then accelerate a beam. This is an important milestone towards producing intense beams of synchrotron light at the pioneering facility, which is the first light-source laboratory in the Middle East.

SESAME, which stands for Synchrotron-light for Experimental Science and Applications in the Middle East, will eventually operate several beamlines at different wavelengths for wide-ranging studies of the properties of matter. Experiments there will enable SESAME users to undertake research in fields ranging from medicine and biology, through materials science, physics and chemistry to healthcare, the environment, agriculture and archaeology.

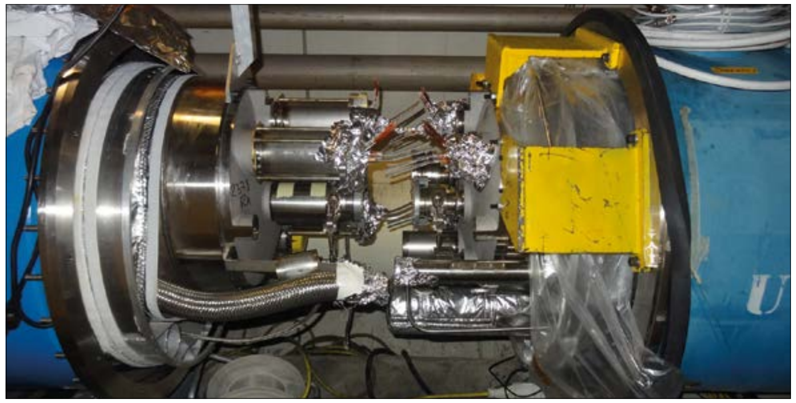
CERN has a long-standing involvement with SESAME, notably through the European Commission-funded CESSAMag project, coordinated by CERN. This project provided the magnet system for SESAME's 42 m-diameter main ring and brought CERN's expertise in accelerator technology to the facility in addition to training, knowledge and technology transfer.

The January milestone follows a series of key events, beginning with the establishment of a Middle East Scientific Collaboration group in the mid-1990s. This was followed by the donation of the BESSY1 accelerator by the BESSY laboratory in Berlin. Refurbished and upgraded components of BESSY1 now serve as the injector for the completely new SESAME main ring, which is a competitive third-generation light source built by SESAME with support from the SESAME members, as well as the European Commission and CERN through CESSAMag, and Italy.

There is still a lot of work to be done before experiments can get underway. Beams have to be accelerated to SESAME's operating energy of 2.5 GeV. Then the synchrotron light emitted as the beams circulate has to be channelled along SESAME's two initial beamlines and optimised for the experiments that will take place there. This process is likely to take around six months, leading to first experiments in the summer of 2017.

LHC NEWS

Machine technical stop in full swing



S Le Naour

Replacing one of the LHC's superconducting dipole magnets is a major task that requires several interconnections to be opened. On the right is a disconnected magnet that was replaced during the current technical stop, fitted with yellow flanges ready for transport.

Following a record year of proton–proton operations at the LHC in 2016, which was followed by a successful proton-lead run, on 5 December 2016 the machine entered a longer than usual winter shutdown. Since then, hundreds of people from CERN's technical teams have been working to repair and upgrade equipment across the whole accelerator chain and also the LHC experiments themselves. The extended year-end technical stop (EYETS), which will be complete by the end of April, has enabled CERN and its users to perform important interventions including the upgrade of the CMS pixel detector.

As the EYETS officially got under way in early December, 10 days were dedicated to powering tests for the LHC magnets to investigate the feasibility of operating at its design energy of 7 TeV per beam. Although this is only 0.5 TeV higher than the energy of the LHC during Run 2, which began in 2015, the LHC's 1232 dipole magnets must be trained at higher currents to allow the higher-energy beams to circulate. Powering tests were conducted in two of the LHC's eight sectors during which the current was gradually increased: in sector 4–5, for example, the current reached 11.535 kA, corresponding to a beam energy of 6.82 TeV. The considerable amount of data collected during the powering tests will now be analysed to define the best strategy for reaching the LHC's full design energy.

The EYETS is now in full swing, with several activities taking place: maintenance of cryogenic, ventilation, vacuum, electrical and other systems; upgrades to the accelerators and injectors for the High-Luminosity LHC (HL-LHC) and LHC Injector Upgrade (LIU) projects; consolidation works; and other activities such as the replacement of two lifts that have been in use since the early days of LEP.

The entire LHC has been emptied of liquid helium, which normally keeps the superconducting dipoles at a temperature of 1.9 K, and the bulk of the machine is being held at a temperature of 20 K during the shutdown. This is to avoid wasting any of the precious gas due to unexpected electrical failures during EYETS activities, and also to allow important maintenance works to be carried out on the cryogenic system. Since it takes several weeks to refill, pump and "boil off" the cryogenics before the LHC can restart operations, the already busy EYETS schedule is extremely tight. Cryo-filling of the first sector is foreseen between the end of February and the beginning of March, with the final cool-down expected in early April.

Another major activity is the replacement of a dipole magnet in sector 1-2, which lies between ATLAS and ALICE. This meant that the sector had to be warmed up to ambient conditions, allowing several tests of its electrical quality and liquid-helium insulation at ambient temperature, which revealed no major issues. One of the major risks of warming up a sector is the deformation of the expansion bellows – the thin corrugated structures that compensate for the contraction and expansion of the quench recovery line for the helium distribution system as the machine is cooled and warmed – but X-ray scans performed on all 250 bellows in this sector show no such problems. In addition, the "ball test", during which a ping-pong ball is fired along the LHC beam-pipe, has been carried out and no faults were found in the sector interconnects.

Regarding the injectors, which transport protons between the various accelerators in the LHC complex, the main EYETS activities concern the Proton Synchrotron Booster (PSB) and the Super Proton Synchrotron (SPS). Critical activities at the PSB include a major de-cabling and cabling campaign, which involves removing all obsolete cables identified during the previous technical stop to make way for the LIU project. Many works are also being carried out on the surface of the PSB to install all the required LIU components.

The SPS is also undergoing a de-cabling and cabling campaign. Other key activities here concern the installation of the cryogenic modules and related infrastructure for the HL-LHC's superconducting crab cavities (see p23), in addition to civil engineering works to prepare for the replacement of the SPS internal beam dump. The poor functioning of this dump last year limited the number of proton bunches that could be injected from the SPS to the LHC, and the new beam dump will be installed during Long Shutdown 2 beginning the end of 2018.

Despite the extensive works taking place and many technical challenges faced, the EYETS schedule is on track with no major disruptions. Once complete, the LHC will be prepared for its 2017 run, for which commissioning will begin in May.

***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.

LHC EXPERIMENTS

LHCb sees first hints of CP violation in baryons

The LHCb experiment has uncovered tantalising evidence that baryons made of matter behave differently to those made of antimatter, violating fundamental charge-parity (CP) symmetry. Although CP-violating processes have been studied for more than 50 years, dating back to the Nobel-prize winning experiment of James Cronin and Val Fitch in 1964, CP violation has only been observed in mesons – that is, hadrons made of a quark and an antiquark. Until now, no significant effects had been seen in baryons, which are three-quark states, despite predictions from the Standard Model (SM) that CP violation also exists in the baryon sector.

Searching for new sources of CP violation, which is one of the main goals of LHCb, could help account for the overwhelming excess of matter over antimatter observed on cosmological scales. Since this excess is too large to be explained by CP violation as described in the SM, other sources must contribute.

The new LHCb result is based on an analysis of data collected during Run 1 of the LHC, from which the collaboration isolated a sample of Λ_b^0 baryons (comprising a beauty, up and down quark) decaying into a proton plus three charged pions. The analysis also selected events in which the antimatter $\overline{\Lambda}_b^0$ baryon decays into an antiproton and three pions. Both of these processes are extremely rare and have never previously been observed. The high production cross-section of beauty baryons at the LHC and the specialised capabilities of the LHCb detector allowed a pure sample of around 6000 such decays to be isolated (figure 1).

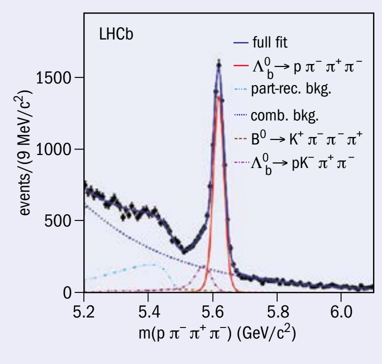


Fig. 1. Mass spectrum of beauty baryons decaying into a proton and three pions (red).

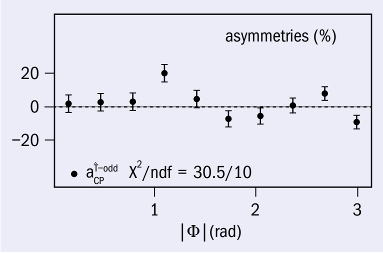


Fig. 2. CP-violating asymmetries measured for beauty baryons in different bins of the kinematical distribution of the four decay products, separated by the so-called Φ variable. The measurements do not agree well with a horizontal line centred on zero, which would be expected for the CP-conserving hypothesis.

By studying the distribution of the four decay products and calculating quantities from the momenta of these final-state particles, it is possible to make detailed comparisons between Λ_b^0 and $\overline{\Lambda}_b^0$ baryons. Any significant difference, or asymmetry, between the quantities for the matter and antimatter cases would be a manifestation of CP violation. In a final refinement to the analysis, this comparison was made in different regions (or bins) mapped out by the kinematics of the decay products. Any CP violation present is expected to vary both in magnitude and sign across phase-space, and hence could be diluted or washed out entirely if not searched for separately in these individual bins.

The LHCb data revealed significant non-zero asymmetries in certain bins (figure 2) and the general pattern of asymmetries across all bins was found to be inconsistent from that which would be expected in the CP-conserving case with a statistical significance of 3.3σ.

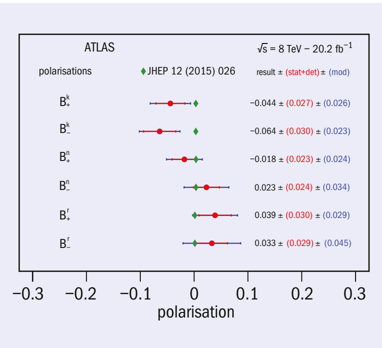
The results, published in *Nature Physics*, will soon be updated with the larger data set collected so far in Run 2. If this signal of CP violation is reproduced and seen with greater significance in the larger sample, the result will be an important milestone in the study of CP violation.

- **Further reading**

LHCb collaboration 2017 *Nature Physics* DOI: 10.1038/NPHYS4021; arXiv:1609.05216.

ATLAS takes a new angle on the top quark

The large mass of the top quark means that the top-quark sector has great potential for gaining a deeper understanding of the Standard Model (SM) and for revealing new physics beyond it. With the large statistics available at the LHC, very precise measurements of the top-quark properties are possible. Two recent analyses performed by ATLAS based on proton–proton collisions recorded at an energy of 8 TeV have allowed the collaboration to probe the angular distributions of the top quark and its decay products in unprecedented detail.



Comparison of the measured polarisations and spin correlations (data points) with Standard Model predictions (diamonds) for the parton-level measurement.

The first analysis concerns the polarisation of W bosons produced in the decays of top-quark–antiquark pairs, which is determined by measuring the angle between the decay products of the W and the b-quark from the top decay. Both leptonic and hadronic W decays were identified, and the fractions of longitudinal, left- and right-handed polarisation states fitted from the angular distributions. The results from ATLAS are the most precise to date and are in good agreement with the SM predictions. This measurement is also used to probe the structure of the Wtb vertex, which could be modified by contributions from new-physics processes and thus allows new constraints to be placed on anomalous tensor and vector couplings.

The goal of the second analysis was to completely characterise the spin-density matrix of the top-quark–antiquark pair production. This required the measurement of 15 independent variables, 10 of which were never previously measured. Specifically, ATLAS measured the polarisation of the top quark and the spin correlation between the top and anti-top along three different spin-quantisation axes: the helicity axis, the axis orthogonal to the production plane created by the directions of the top quark and the beam axis, and a third axis orthogonal to the former two. Using this scheme, the collaboration was able to measure new "cross-correlation" observables for the first time, based on the angular distributions of the leptons from the top-quark decays. The distributions were corrected back to generator-level to allow the results to be interpreted in terms of new physics models, and so far all results are in agreement with the SM expectations.

These studies of the angular distributions of top-quark decays will benefit from the larger data sample collected at 13 TeV, allowing stronger constraints to be placed on potential new-physics contributions or opening new opportunities to observe deviations from the SM.

- **Further reading**

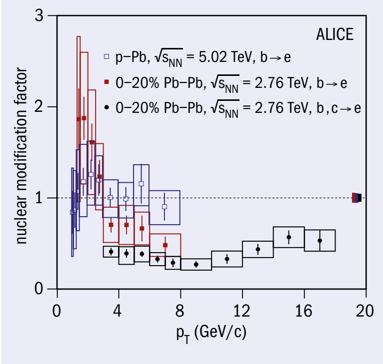
ATLAS Collaboration 2016 arXiv:1612.07004.
ATLAS Collaboration 2016 arXiv:1612.02577.

ALICE studies beauty in the quark–gluon plasma

In high-energy nucleus–nucleus collisions, heavy-flavour quarks (charm and beauty) are produced on a very short time scale in initial hard-scattering processes and thus they experience the entire evolution of the collision. Such quarks are valuable probes to study the mechanisms of energy loss and hadronisation in the hot and dense matter, the quark–gluon plasma, formed in heavy-ion collisions.

To investigate these effects, proton–proton (pp) and proton–lead (p–Pb) collisions are measured as a reference. While the former allows the study of heavy-flavour production when no medium is formed, the latter gives access to cold nuclear matter effects, namely parton scattering in the initial state and modifications of the parton densities in the nucleus.

The excellent electron identification capabilities and track impact parameter resolution of the ALICE detector enable measurements of electrons from heavy-flavour hadron decays at mid-rapidity. To study the predicted quark mass dependence of the parton energy loss, the contributions of electrons from charm- and beauty-hadron decays are statistically separated using the different impact parameter distributions as a proxy for their decay length and empirical estimations of the background.



Nuclear modification factors of electrons from beauty-hadron decays at mid-rapidity for p–Pb and central Pb–Pb collisions.

The measurement of electrons from heavy-flavour hadron decays in p–Pb collisions shows no indication of a modification of the production with respect to pp collisions at high transverse momentum (p_T), indicating that cold nuclear matter effects are small. The observed reduction in yield at high p_T in central Pb–Pb collisions relative to pp interactions can thus be attributed to the presence of the hot and dense medium formed in Pb–Pb collisions. This implies that beauty quarks interact with the medium.

The larger suppression of electrons from both charm- and beauty-hadron decays compared with the beauty-only measurement is consistent with the ordering of charm and beauty suppression seen previously in the comparison of prompt D mesons (measured by ALICE) and J/ψ from B meson decays (measured by CMS). The larger samples of Pb–Pb collisions in Run 2 will improve the precision of the measurements and will make it possible to determine if beauty quarks participate in the collective expansion of the quark–gluon plasma.

- **Further reading**

ALICE Collaboration 2016 arXiv:1609.03898.
ALICE Collaboration 2016 arXiv:1609.07104.
ALICE Collaboration 2015 *JHEP* **1511** 205.

CMS probes non-standard Higgs decays to ττ

Recently, the CMS collaboration performed an updated search for a neutral Higgs boson decaying into two τ leptons using 13 fb^{-1} of data recorded during 2016. Although the existence of the Higgs has been established beyond doubt since its debut in the CMS and ATLAS detectors in 2012, the vast majority of Higgs bosons recorded so far concern its decay into pairs of bosons. Observing the Higgs via its decays into pairs of fermions further tests the predictions of the Standard Model (SM). In particular, τ leptons have played a major role in measuring the Yukawa couplings between the Higgs and fermions, and thus proved to be an important tool for discovering new physics at the LHC.

CMS first reported evidence for Higgs to ττ decays in 2014. With a lifetime of around 10^{-13} seconds and a mass of 1.776 GeV, τ leptons present a unique but challenging experimental signature at hadron colliders. Their very short lifetime means that τ particles decay in the LHC beam pipe before reaching the inner layers of the CMS detector. Approximately 35% of the time, the τ decays into two neutrinos plus a lighter lepton, while 65% of the time it decays into a single neutrino and hadrons. τ decays yield low charged and neutral particle multiplicities: more than 95% of the hadronic decays contain just one or three charged hadrons and less than two

▷

neutral pions. The primary difficulty when dealing with the τ is the distinction between genuine τ leptons and copiously produced quark and gluon jets that can be misidentified as taus.

To identify the dominant τ decay modes, CMS has developed a powerful τ reconstruction algorithm, which makes use of the single-particle reconstruction procedure (called particle flow). Charged hadrons are combined with photons from neutral pion decays to reconstruct τ decay modes with one or three charged hadrons and neutral pions (figure 1). The algorithm also pays particular attention to the effects of detector materials in converting photons into electron–positron pairs. The large magnetic field of CMS causes secondary electrons to bend, resulting in broad signatures in the phi (azimuthal) co-ordinate, and "strips" are created by clustering photons and electrons via an iterative process. In a new development for LHC Run 2, the strip size is allowed to vary based on the momentum of the clustered candidates.

Applying the latest τ algorithm, along with numerous other analysis techniques, CMS finds no excess of events in which a Higgs decays into two τ leptons compared to the expectation from the SM. Instead, upper limits were determined for the product of the production cross-section and branching fraction for masses in the region 90–3200 GeV, and the results were also interpreted in the context of the Minimal Supersymmetric SM (MSSM) (figure 2). The LHC is now operating at its highest energy and an increase in instantaneous luminosity is planned. The next few years of operations will therefore be vital for further testing the SM and MSSM using the τ lepton as a tool.

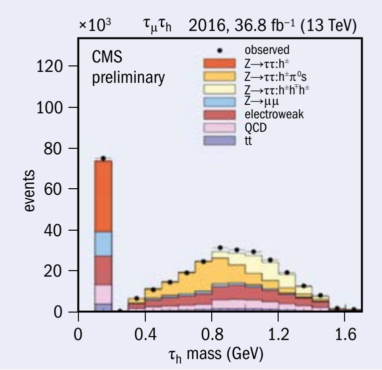


Fig. 1 Mass of the τ lepton in hadronic decay modes using reconstruction techniques developed by the CMS collaboration.

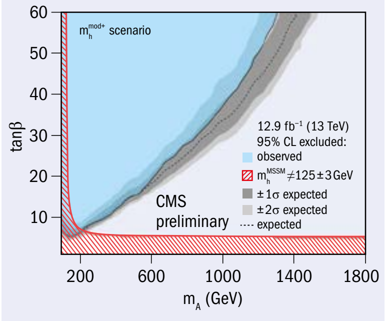


Fig. 2. Interpreting the results of a search for a neutral Higgs boson decaying into two τ leptons in the context of the Minimal Supersymmetric Standard Model, showing exclusion limits in the m_A-tan β plane for the m^{mod+} scenario. The red contour indicates the region that does not yield a Higgs boson consistent with a mass of 125 GeV within the theoretical uncertainties of ±3 GeV.

- **Further reading**

CMS Collaboration 2014 JHEP 05 104.
CMS Collaboration CMS-PAS-TAU-16-002.

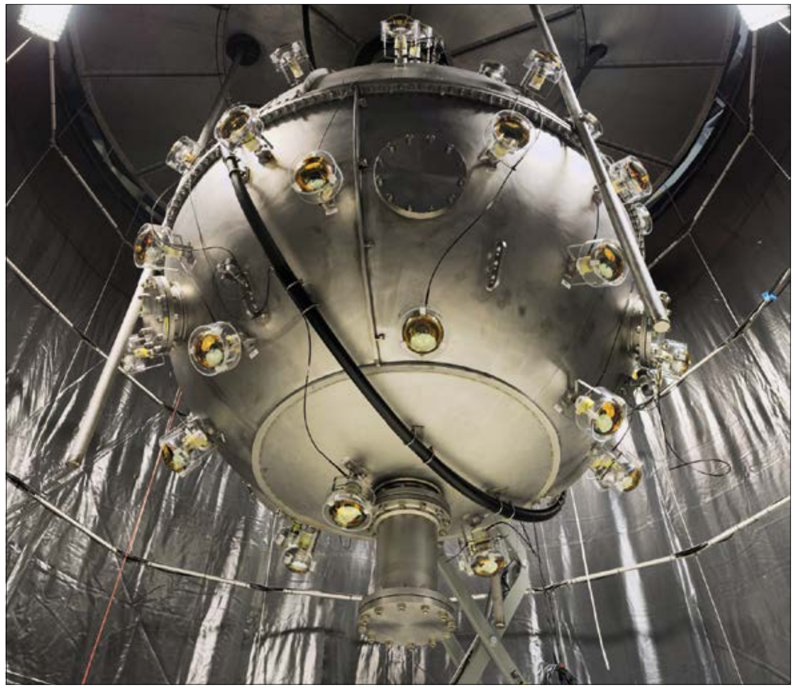
FACILITIES

Funding injection for SNOLAB

The SNOLAB laboratory in Ontario, Canada, has received a grant of $28.6m to help secure its next three years of operations. The facility is one of 17 research facilities to receive support through Canada's Major Science Initiative (MSI) fund, which exists to secure state-of-the-art national research facilities.

SNOLAB, which is located in a mine 2 km beneath the surface, specialises in neutrino and dark-matter physics and claims to be the deepest cleanroom facility in the world. Current experiments located there include: PICO and DEAP-3600, which search for dark matter using bubble-chamber and liquid-argon technology, respectively; EXO, which aims to measure the mass and nature of the neutrino; HALO, designed to detect supernovae; and a new neutrino experiment SNO+ based on the existing SNO detector.

The new funds will be used to employ the 96-strong SNOLAB staff and support the operations and maintenance of the lab's facilities.



SNOLAB

The second-generation DEAP-3600 detector at SNOLAB, which uses 3600 kg of liquid argon to search for WIMPs.

MEDICAL ACCELERATORS

GSI ions target irregular heartbeat

Researchers at the GSI Helmholtz Center for Heavy Ion Research in Darmstadt, Germany, have demonstrated the feasibility of using carbon ions to treat cardiac arrhythmia, in which abnormal electrical patterns can lead to sudden heart failure or permanent damage as a result of stroke. Conventional treatments for certain forms of cardiac arrhythmia include drugs or "catheter ablation," in which catheters are guided through blood vessels to the heart to destroy certain tissue. The GSI team, in conjunction with physicians from Heidelberg University and the Mayo Clinic in the US, have now shown that high-energy carbon ions produced by a particle accelerator can in principle be used to perform such treatments without catheters.

The non-invasive procedure induces specific changes to cardiac tissue that prevent the transmission of electrical signals, permanently interrupting the propagation of disruptive impulses. Following promising results from initial tests on cardiac cell cultures and beating-heart preparations, the researchers developed an animal study. Further detailed studies are needed, however, before the method can start to benefit patients.

A crucial advantage of the new method it that the ions can penetrate to any desired depth. Irradiating cardiac tissue with carbon ions appears as a promising, non-invasive alternative to catheters, and ultimately ion-based procedures are expected to take a few minutes compared with a few hours. "It is exciting that the carbon beam could work with surgical precision in particularly sensitive areas of the body," says Paolo Giubellino, scientific managing director of FAIR and GSI and former spokesperson of the LHC's ALICE experiment at CERN. "We're proud that the first steps toward a new therapy have now been taken."

A Zschau/GSI

The GSI accelerator facility was used to study the treatment possibilities for cardiac arrhythmia with ions.

- **Further reading**

H Immo Lehmann *et al.* 2016 *Scientific Reports* **6** 38895.

Sciencewatch

Compiled by John Swain, Northeastern University

Early vegetable cooking

Humans started using thermally resistant cooking vessels some 15,000 years ago, opening new food groups and leading to major changes in diet and nutrition. Research shows that such vessels were routinely used to process animal products, but until now there has been no evidence of early plant cooking. A new study by Richard Evershed of the University of Bristol in the UK and colleagues reports the earliest direct evidence for plant processing at two archeological sites in the Libyan Desert, dating to 8200–6400 BC. A total of 110 broken ceramic pieces from the early to middle Holocene periods were analysed using gas chromatography and mass spectrometry, revealing distributions typical of both animal fat and plant origins. Some samples contained both, indicating that plants and animal products were processed together or that the vessels were used for multiple purposes. The distinctive lipid profile from the vessels demonstrated the processing of a broad variety of plants, including seeds, leafy terrestrial and aquatic plants. The advent of plant cooking would have had a significant impact on human nutrition, health and energy, and the preparation of cooked foods soft enough for infants to ingest could have led to earlier weaning and thus enhanced fertility.


The Archaeological Mission in the Sahara/Sapienza University of Rome

Archaeobotanical remains from the Libyan site, dated approximately 8000 BC.

● **Further reading**
J Dunne *et al.* 2016 *Nature Plants* **3** 16194.

Alcohol and hunger

People have enjoyed an apéritif to stimulate appetite since at least the 5th century AD. While popular explanations for alcohol-induced overeating include a reduction of self-control, Sarah Cains of the Francis Crick Institute in London and colleagues have now identified a physiological mechanism. Giving mice alcohol for a period of three days increased their food intake and boosted the activity of AgRP neurons, which trigger feelings of intense hunger when stimulated. The activity level was similar to that induced by fasting or hunger hormones, and mice that had these cells silenced did not increase the amount they ate.

● **Further reading**
S Cains *et al.* 2017 *Nature Communications* **8** 14014.

Colourful qubits

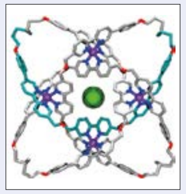
Single photons can now be prepared in a quantum-mechanical superposition of colours, giving rise to a new qubit that could be useful in quantum-information processing. Stéphane Clemmen of Cornell University in the US and colleagues combined single photons in a single stream with photons from two strong laser pumps in a cryogenically cooled 100 m-long optical fibre, bumping their energy up and down and thus placing them in a superposition of two colours.

● **Further reading**
S Clemmen *et al.* 2016 *Phys. Rev. Lett.* **117** 223601.

Molecules form tightest knot

David Leigh and colleagues of the University of Manchester in the UK have tied the world's tightest knot, in the form of an organic molecule. The knot has eight non-alternating crossings in a 192 atom closed loop measuring about 20 nm long, and is made from many benzene rings strung together with octahedral iron(II) ions controlling the relative positions of the three strands at each crossing point. Knots may ultimately prove just as versatile and useful at the nanoscale as at the macroscale, says the team, but a lack of synthetic routes to all but the simplest molecular knots currently prevents systematic investigations of the influence of knotting at the molecular level.

● **Further reading**
J Danon *et al.* 2017 *Science* **355** 159.


The knot showing carbon (light grey and turquoise in one repeat unit of the knot), nitrogen (blue), oxygen (red) and iron (purple) atoms.

How the penis bone got lost

The penis bone, or baculum, rests at the end of the penis and provides structural support during copulation in many mammals, although not in humans. Matilde Brindle and Christopher Opie of University College London in the UK have analysed the baculums of nearly 2000 mammal species including primates and carnivores, finding that species that copulate for longer periods have longer bacula, as do those with more than one mate or with seasonal breeding patterns. The baculum first evolved 145–195 million years ago in the common ancestor of carnivores and primates, and disappeared in humans when we split from chimpanzees. This may have coincided with the change towards a more monogamous lifestyle, concludes the team.

● **Further reading**
M Brindle and C Opie 2016 *Proc. Roy. Soc. B* **283** 20161736.

Superconducting bismuth raises questions

Bulk superconductivity has been observed in bismuth when it is cooled to a temperature below 0.53 mK at ambient pressure. The discovery, reported by S Ramakrishnan and colleagues of the Tata Institute of Fundamental Research in Mumbai, India, is a surprise because conventional Bardeen–Cooper–Schrieffer theory cannot explain it. Since the Debye temperature and the Fermi level are comparable in this system, something other than phonon-mediated pairing seems to be required.

● **Further reading**
O Prakash *et al.* 2017 *Science* **355** 52.

Astrowatch

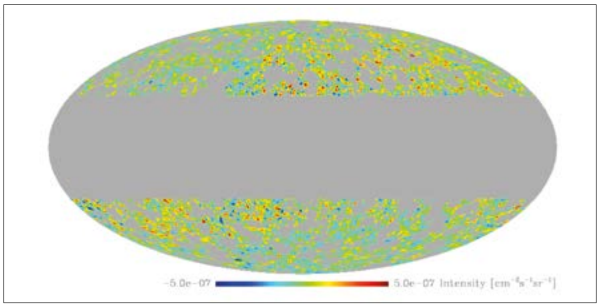
Compiled by Marc Türler, ISDC and Observatory of the University of Geneva, and CHIPP, University of Zurich

WIMP no-show in gamma-ray background

Although the night sky appears dark between the stars and galaxies that we can see, a strong background emission is present in other regions of the electromagnetic spectrum. At millimetre wavelengths, the cosmic microwave background (CMB) dominates this emission, while a strong X-ray background peaks at sub-nanometre wavelengths. For the past 50 years it has also been known that a diffuse gamma-ray background at picometre wavelengths also illuminates the sky away from the strong emission of the Milky Way and known extra-galactic sources.

This so-called isotropic gamma-ray background (IGRB) is expected to be uniform on large scales, but can still contain anisotropies on smaller scales. The study of these anisotropies is important for identifying the nature of the unresolved IGRB sources. The best candidates are star-forming galaxies and active galaxies, in particular blazars, which have a relativistic jet pointing towards the Earth. Another possibility to be investigated is whether there is a detectable contribution from the decay or the annihilation of dark-matter particles, as predicted by models of weakly interacting massive particles (WIMPs).

Using NASA's Fermi Gamma-ray Space Telescope, a team led by Mattia Fornasa from the University of Amsterdam in the Netherlands studied the anisotropies of the IGRB in observations acquired over more than six years. This follows earlier results published in 2012 by the Fermi collaboration and shows that there are two different classes of gamma-ray sources. A specific type of blazar appears to dominate at the highest energies, while at lower frequencies star-forming galaxies or another class of blazar is thought to imprint a steeper spectral slope in the IGRB. A possible additional contribution from WIMP annihilation could not be identified by Fornasa and collaborators.



M Fornasa, UvA/Grappa

Fluctuations in the isotropic gamma-ray background (IGRB), based on 81 months of Fermi data. Emissions from our own galaxy and from bright extra-galactic sources are masked in grey.

The first step in such an analysis is to exclude the sky area most contaminated by the Milky Way and extra-galactic sources, and then to subtract remaining galactic contributions and the uniform emission of the IGRB. The resulting images include only the IGRB anisotropies, which can be characterised by computing the associated angular power spectrum (APS) similarly to what is done for the CMB anisotropies. The authors do this both for a single image ("auto-APS") and between images recorded in two different energy regions ("cross-APS").

The derived auto- and cross-APS are found to be consistent with a Poisson distribution, which means they are constant on all angular scales. This absence of scale dependence in gamma-ray anisotropies suggests that the main contribution comes from distant active galactic nuclei. On the other hand, the emission by star-forming galaxies and dark-matter structures would be dominated by their local distribution that is less uniform on the sky and thus would lead to enhanced power at characteristic angular scales. This allowed Fornasa and co-workers to derive exclusion limits on the dark-matter parameter space. Although less stringent than the best limits achieved from the average intensity of the IGRB or from the observation of dwarf spheroidal galaxies, they independently confirm the absence, so far, of a gamma-ray signal from dark matter.

The constraints on dark matter will improve with new data continuously collected by Fermi, but a potentially more promising approach is to complement them at higher gamma-ray energies with data from the future Cherenkov Telescope Array and possibly also with high-energy neutrinos detected by IceCube.

● Further reading

M Fornasa *et al.* 2016 *Phys. Rev. D* **94** 123005.

Picture of the month

This composite multi-wavelength image invokes thoughts of a frosty winter landscape. In reality, it is a rather hot place in our Galaxy about 5500 light-years from Earth in the constellation Scorpius. The region called NGC 6357 is an association of at least three clusters of young stars, including many hot, massive luminous stars. The purple-coded X-ray emission is based on observations from the Chandra X-ray Observatory and from the earlier ROSAT satellite, and reveals hundreds of point sources, which are young stars, as well as diffuse emission from hot interstellar gas bubbles. The orange-coded infrared observations from NASA's Spitzer Space Telescope trace dusty filaments of cold gas surrounding these cavities, while blue is used for the optical emission observed by the UK Infrared Telescope. Such star-forming clouds are called "HII" (pronounced "H-two") regions, because the intense UV emission of the newborn stars photo-ionises the hydrogen gas.

NASA/CXC/PSU/L Townsley *et al.*; UKIRT; NASA/JPL-Caltech

The outer (warm) vessel for the single-phase protoDUNE at CERN. The red steel frame provides support for the cold-membrane cryostat, the detector, and approximately 800 tonnes of liquid argon. (Image credit: M Brice/CERN.)

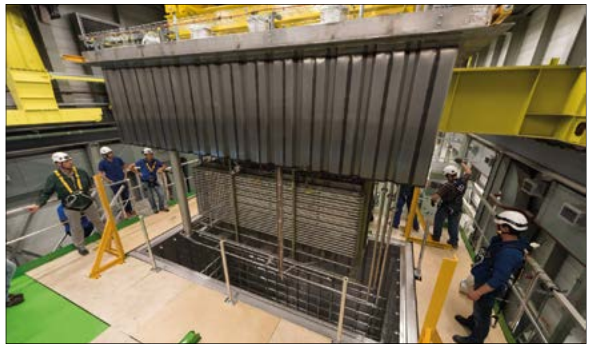
ProtoDUNE revealed

CERN makes rapid progress towards prototype detectors for the international DUNE experiment.

This 11 m-high structure with thick steel walls will soon contain a prototype detector for the Deep Underground Neutrino Experiment (DUNE), a major international project based in the US for studying neutrinos and proton decay. It is being assembled in conjunction with CERN's Neutrino Platform, which was established in 2014 to support neutrino experiments hosted in Japan and the US (*CERN Courier* July/August 2016 p21), and is pictured here in December as the roof of the structure was lowered into place. Another almost identical structure is under construction nearby and will house a second prototype detector for DUNE. Both are being built at CERN's new "EHN1" test facility, which was completed last year at the north area of the laboratory's Prévessin site.

DUNE, which is due to start operations in the next decade, will address key outstanding questions about neutrinos. In addition to determining the ordering of the neutrino masses, it will search for leptonic CP violation by precisely measuring differences between the oscillations of muon-type neutrinos and antineutrinos into electron-type neutrinos and antineutrinos, respectively (*CERN Courier* December 2015 p19). To do so, DUNE will consist of two advanced detectors placed in an intense neutrino beam produced at Fermilab's Long-Baseline Neutrino Facility (LBNF). One will record particle interactions near the source of the beam before the neutrinos have had time to oscillate, while a second, much larger detector will be installed deep underground at the Sanford Underground Research Laboratory in Lead, South Dakota, 1300 km away.

In collaboration with CERN, the DUNE team is testing technology for DUNE's far detector based on large liquid-argon (LAr) time-projection chambers (TPCs). Two different technologies are being considered – single-phase and double-phase LAr TPCs – and the eventual DUNE detectors will comprise four modules, each with a total LAr mass of 17 kt. The single-phase technique is well established, having been deployed in the ICARUS experiment at Gran Sasso, while the double-phase concept offers potential advantages. Both may be used in the final DUNE far detector. Scaling LAr technology to such industrial levels presents several challenges – in particular the very large cryostats required, which has led the DUNE collaboration to use technological solutions ▷


M Brice/CERN

Insertion of the 3 × 1 × 1 m^3 technology demonstrator in the cryostat of the dual-phase protoDUNE module.

inspired by the liquified-natural-gas (LNG) shipping industry.

The outer structure of the cryostat (red, pictured on previous page) for the single-phase protoDUNE module is now complete, and an equivalent structure for the double-phase module is taking shape just a few metres away and is expected to be complete by March. In addition, a smaller technology demonstrator for the double-phase protoDUNE detector is complete and is currently being cooled down at a separate facility on the CERN site (image left). The 3 × 1 × 1 m^3 module will allow the CERN and DUNE teams to perfect the double-phase concept, in which a region of gaseous argon situated above the usual liquid phase provides additional signal amplification.

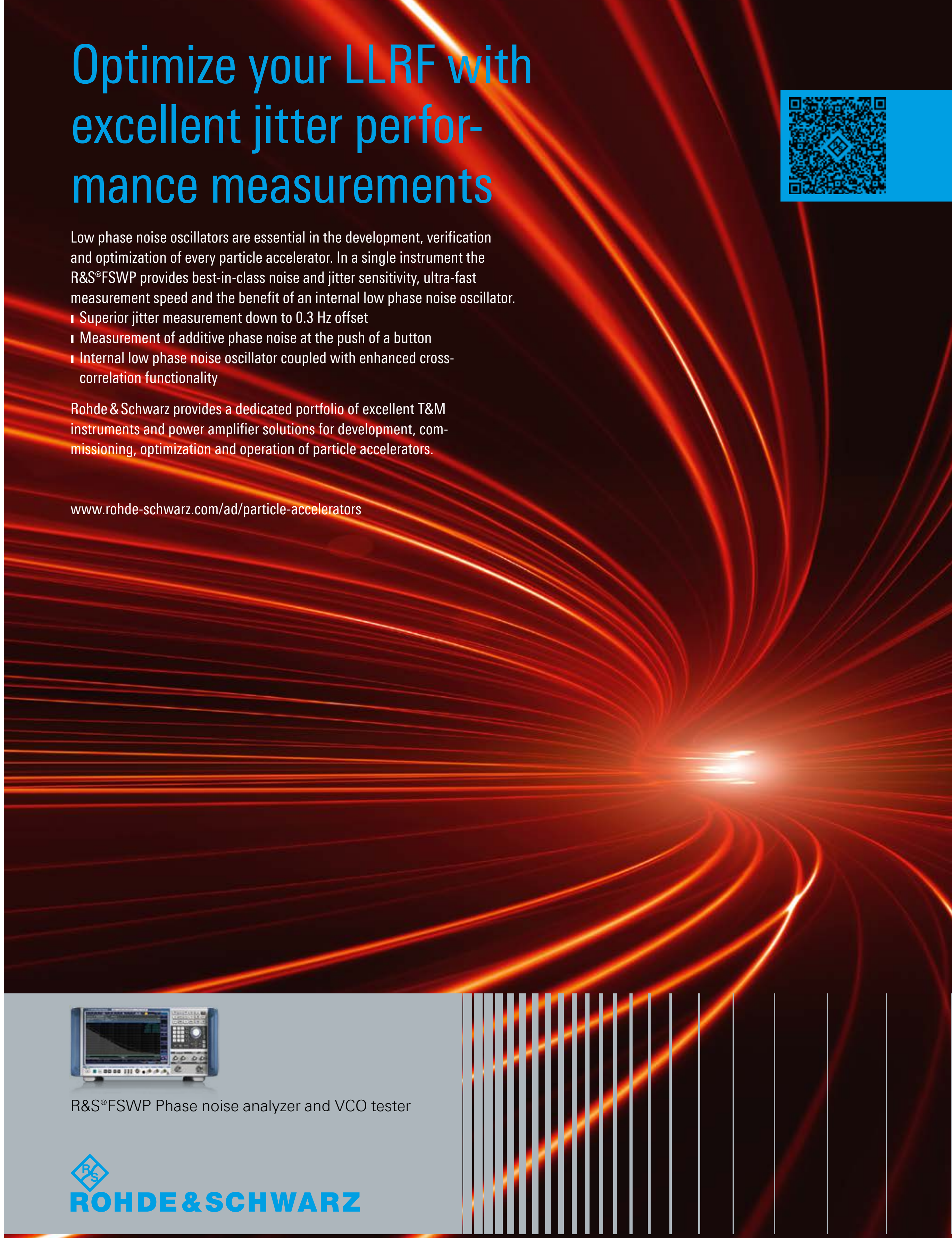
The large protoDUNE modules are planned to be ready for test beam by autumn 2018 at the EHN1 facility using dedicated beams from the Super Proton Synchrotron. Given the intensity of the future LBNF beam, for which Fermilab's Main Injector recently passed an important milestone by generating a 700 kW, 120 GeV proton beam for a period of more than one hour, the rate and volume of data produced by the DUNE detectors will be substantial. Meanwhile, the DUNE collaboration continues to attract new members and discussions are now under way to share responsibilities for the numerous components of the project's vast far detectors (see p41).

Résumé

ProtoDUNE évolue

La plateforme neutrino du CERN progresse rapidement dans la création de grands modules prototypes pour l'expérience internationale DUNE, aux États-Unis. Celle-ci étudiera les neutrinos produits au Fermilab, à 1 300 km de distance. Deux modules de 8 m de long seront équipés d'une technologie novatrice utilisant de l'argon liquide, afin d'étudier des questions telles que la hiérarchie des masses des neutrinos.

Matthew Chalmers, CERN.



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Superconducting niobium-tin cables being wound on the Spirex coil winder at Fermilab. (All image credits: J Ordan/CERN.)

On the trail of the HL-LHC magnets

Designing and building the advanced accelerator structures for CERN's High-Luminosity LHC is a major challenge that requires international collaboration. **Paola Catapano** tours two labs in the US that are helping to develop superconducting focusing magnets and crab cavities for the project.

Inside the IB3 Tech Building at Fermilab on the outskirts of Chicago, a heavy-duty machine several metres long slowly winds a flat superconducting cable. Watching the bespoke coil winder – called the Spirex and manufactured by Italian firm SELVA – in action, and the meticulous attention to detail from the coil's specialist operators, is mesmerising. Their task is to fabricate the precision coils that will form the core of novel magnets for CERN's High-Luminosity LHC (HL-LHC) project, scheduled to begin operation in the early 2020s. "It has to make 50 turns in total, 22 on the inner layer and 28 on the outer," explains Fred Nobrega, of Fermilab's magnet-systems department. The main challenge is the niobium-tin (Nb$_3$Sn) material, he says. "Bend it and it breaks like spaghetti."

▷

Fermilab's Giorgio Apollinari in the former assembly hall of the CDF experiment, where preparations for HL-LHC magnets are under way (top); flat Nb$_3$Sn cables, coloured white after treatment with glass fibre to insulate each spire, are slowly fed from the coil winder to form prototype dipole magnets for the HL-LHC (middle and above).

The HL-LHC magnets will be built from Nb$_3$Sn, a new conductor used for the first time in an accelerator. Unlike copper, however, Nb$_3$Sn is extremely brittle. Winding turns around the ends of the coil is particularly difficult, says Nobrega, and new chemical and heat treatments are being developed in the current R&D phase of the project at Fermilab to address this issue. The aim is to move from the prototype stage directly to the mass production of 45 long coils that are uniform and of high quality. A further 45 coils will be manufactured more than 1000 km away at Brookhaven National Laboratory (BNL).

The HL-LHC relies on a number of innovative magnet and accelerating technologies, most of which are not available off-the-shelf. Key to the new accelerator configuration are powerful superconducting dipole and quadrupole magnets with field strengths of 11 and 12 T, respectively (for comparison, the superconducting niobium-titanium dipoles that guide protons around the existing LHC have fields of around 8.3 T. The new quadrupoles will be installed on either side of the LHC collision points to increase the total number of proton–proton collisions by a factor 10, therefore boosting the chances of a discovery. Although the project requires modifications to just 5% of the current LHC configuration (see article on p28), each one of the HL-LHC's key innovative technologies pose exceptional challenges that involve several institutes around the world.

Magnets of choice

Fermilab has a glorious history in superconductivity. It was here that the first large superconducting magnet accelerator was built, for example. "But more than that, it was shown that [superconducting magnets] could be reliably employed in a collider experiment for hours and hours of stable beams," says physicist Giorgio Bellettini, who was spokesperson of the CDF experiment at Fermilab's Tevatron collider during the mid-1990s at the time the top quark was discovered there. "The LHC experience is built upon this previous large endeavour."

The plan is to develop and build half of the focusing magnets for the HL-LHC in the US. These have the specific project labels Q1 and Q3, and are a collaboration between three laboratories: Fermilab, BNL and Lawrence Berkeley National Laboratory in California. Nb$_3$Sn technology, whose development has been supported by the US Department of Energy, was not applicable to accelerator magnets until around a decade ago. Now, Nb$_3$Sn magnets are the technology of choice. The prototypes being developed here are 4 m long, and once assembled with the surrounding "cold mass" to keep them below the superconducting operational temperature of Nb$_3$Sn, they will grow to around twice this length.

The innovative feature of these magnets is their very large aperture – 150 mm in diameter – which is necessary to focus the proton beams more tightly in the interaction points. It also allows greater control of the stress on the magnets and the coils induced by the large magnetic field, explains Giorgio Apollinari, who joined Fermilab in the early days and is now director of the US LHC Accelerator Research Program (LARP). No magnet today can achieve fields of 12 T with such a big opening, which is three times larger than that of the existing LHC dipoles. This is a new development introduced by the LARP team, explains Apollinari, and it took several years to go from 70, then 90 to 120 and now 150 mm required by the HL-LHC. "And then you have to have all the infrastructure necessary to build the magnets, test the magnets, make sure they work, measure the field quality and hopefully send them to CERN for installation in the beamline in 2025."

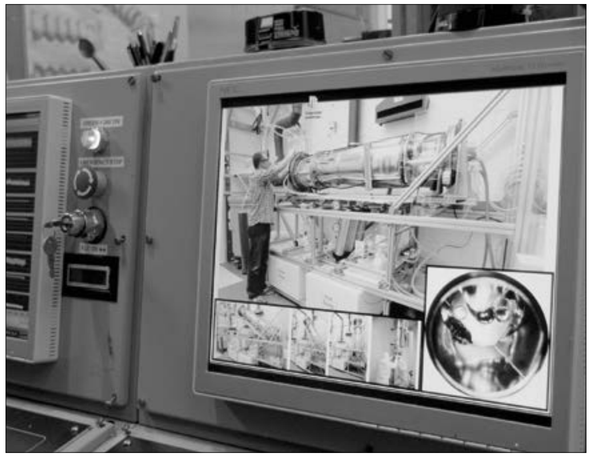
Fermilab and the other LARP laboratories have successfully built 1 m-long short models to demonstrate that the technology meets the technical requirements, and the components are working exactly as expected. Now the teams are building longer prototypes with the correct length, aperture and all other design features. The next step is to build a full prototype with four coils, to complete the quadrupole configuration of the magnets, this coming spring. Similar magnets are being prototyped at CERN with a more ambitious length of 7.5 m. The final product from the US will be a 60 cm-diameter 4 m-long basic magnet containing a hole for the HL-LHC beam pipe. Twenty of these structures will be built in total, 10 in the US and 10 at CERN, of which 16 will be installed and the rest kept as spares. "This is collaboration in physics at its best," explains Apollinari. "Everybody is trying to go faster, but we are looking at what each other does openly and learning from each other."

Focus on cavities

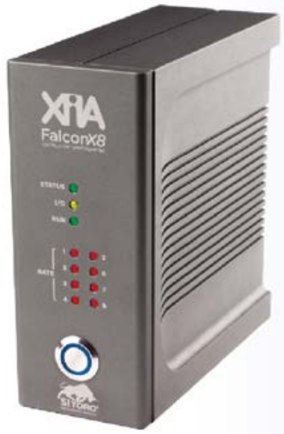
Over at Fermilab's sister laboratory, Argonne National Laboratory (ANL) some 40 km away, the other substantial part of the US contribution to the HL-LHC project is gathering pace. This involves novel "crab"-cavity technology, which is needed both to increase the luminosity and reduce so-called beam–beam parasitic effects that limit the collision efficiency of the accelerator. Unlike standard radiofrequency cavities, which accelerate charged particles in the direction along their path, crab cavities provide a transverse deflection of the beam which causes it to rotate.

The cavities are made from pure niobium and therefore require strict control from contamination via chemical processing. ANL specialises in superconducting cavities with a wide range of geometries, and a joint facility for the chemical processing of cavities is in place. ANL's extensive experience with superconducting cavities includes the Argonne Tandem Linac Accelerator System (ATLAS). Built and operated by the physics division, this is the world's first superconducting linear accelerator for heavy ions, working at energies in the vicinity of the Coulomb barrier to study the properties of the nucleus. It is for this machine that niobium was used for the first time in an accelerator, in 1977, and for which "quarter-wave" superconducting cavities were developed. "We developed superconducting cavities for a whole variety of projects, for the ATLAS accelerator, Fermilab, BNL, SLAC and of course for the HL-LHC at CERN," says ANL accelerator scientist Michael Kelly. We meet in the lobby of the ANL physics division, next to a piece of the laboratory's history: Enrico Fermi's

ANL specialises in superconducting cavities with a wide range of geometries.



The clean room (top) and the view from its control room (middle) at ANL, where researchers are developing pure niobium structures for the HL-LHC's superconducting crab cavities. Chemical processing taking place at a separate Argonne facility (above).



original "chopper", a mechanical rotating shutter to select neutrons built in 1947 as part of ANL's original nuclear-physics programme. "Today we process crab cavities for the HL-LHC, trying to achieve the highest possible accelerating or crabbing voltages, by making a very very clean surface on the cavity," he explains.

ANL's chemical processing facility has recently been enlarged to accommodate new buffer chemical polishing and electropolishing rooms. Wearing a complete set of clean-room garments as we enter the facility, electronic engineer Brent Stone explains the importance of surface processing. "A feature of niobium is that a damaged layer is formed as it is mined from the ground and goes through all different processes, so when the niobium is transformed into cavities we need to remove a 120–150 μm-thick damaged layer," he says. "Inside these layers you can have inclusions that may affect their performance and it is critical to remove them."

Several steps, and journeys, are required to process the cavities. After the application of acids to remove material from the surface, the cavities undergo two cycles in ultrasonic tanks before being rinsed at high pressure and returned to Fermilab to be degassed in vacuum at high temperatures. They are then taken back to ANL for final chemical treatment, cleaning and assembly in the clean room. Finally, the cavities processed at Argonne are sent to BNL were they are cooled down to liquid-helium temperatures to test if they meet the crabbing voltage required for the HL-LHC. "One of the cavities processed has just very easily achieved its design goal," says Kelly proudly, before we take leave of the laboratory.

Next stop CERN

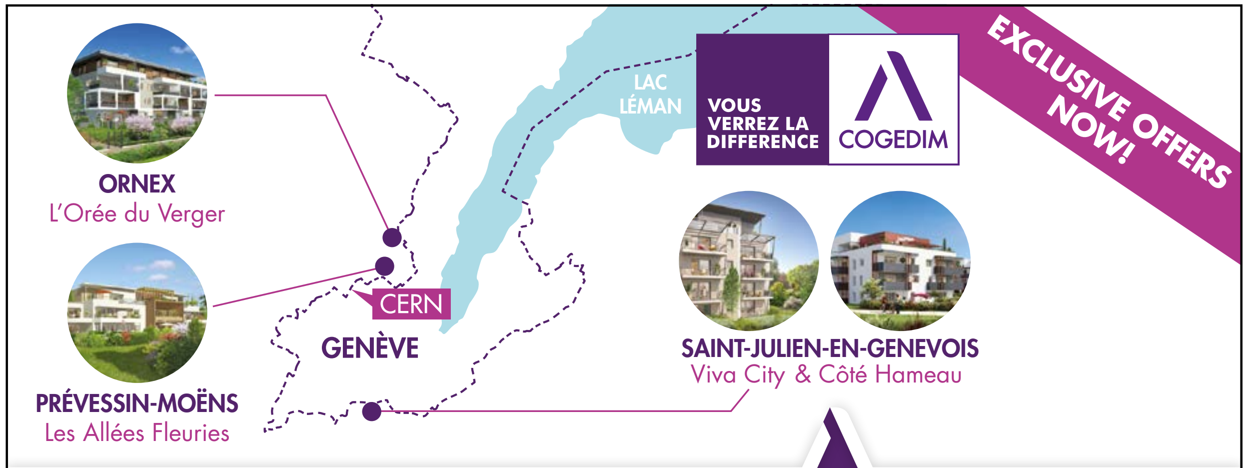
The crab cavities are less advanced than the magnets for the HL-LHC, both at CERN and at Fermilab. But efforts are progressing on schedule on both sides of the Atlantic. Two different designs have been developed for the HL-LHC interaction points: vertical plane for ATLAS and horizontal plane for CMS. Both cavity designs originated from LARP, the LHC accelerator R&D programme created by the DOE in 2005 while the LHC was nearing its completion. "Without that foresight we wouldn't have the HL-LHC today," says Apollinari.

Résumé

Sur les traces des aimants du HL-LHC

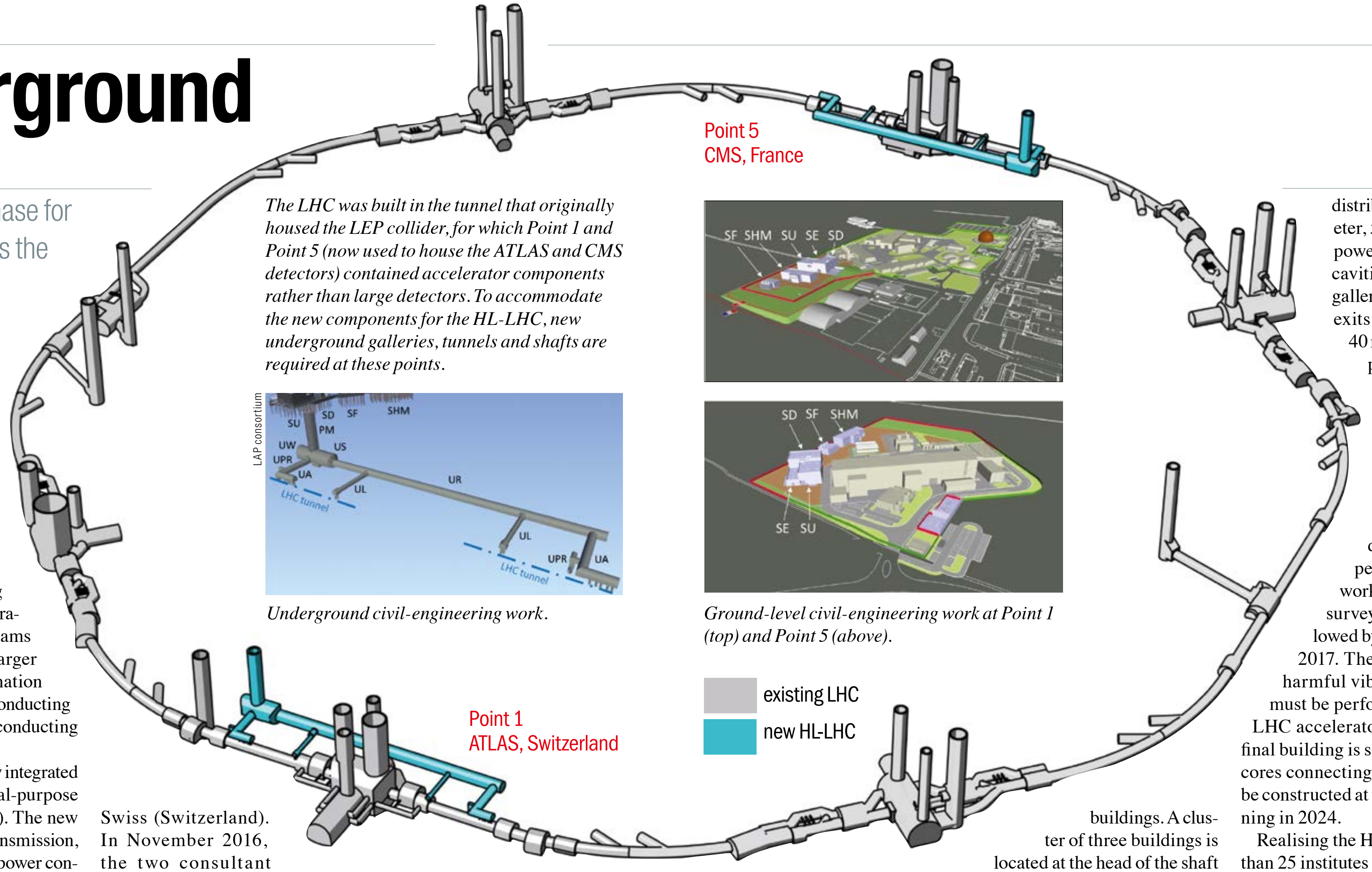
La conception et la construction des structures avancées destinées au projet LHC à haute luminosité (HL-LHC) du CERN représentent un défi de taille, pour lequel une collaboration internationale est nécessaire. Paola Catapano a visité aux États-Unis deux laboratoires qui y participent. Le Fermilab, près de Chicago, contribue à développer des aimants supraconducteurs pour le HL-LHC, formés d'un alliage de niobium et d'étain qui doit être manipulé avec une extrême précaution. Au Laboratoire national d'Argonne, les équipes travaillent quant à elles sur des structures en niobium pur, destinées aux cavités en crabe novatrices du HL-LHC. Pendant ce temps, des activités semblables ont lieu au CERN en vue de cette importante amélioration du LHC.

Paola Catapano, CERN.



Going underground

Completion of the preliminary design phase for the High-Luminosity LHC last year paves the way for civil-engineering work to begin.



The LHC was built in the tunnel that originally housed the LEP collider, for which Point 1 and Point 5 (now used to house the ATLAS and CMS detectors) contained accelerator components rather than large detectors. To accommodate the new components for the HL-LHC, new underground galleries, tunnels and shafts are required at these points.

Underground civil-engineering work.

Ground-level civil-engineering work at Point 1 (top) and Point 5 (above).

▨ existing LHC

🟦 new HL-LHC

The High-Luminosity LHC (HL-LHC) project at CERN is a major upgrade that will extend the LHC's discovery potential significantly. Approved in June 2014 and due to enter operation in the mid-2020s, the HL-LHC will increase the LHC's integrated luminosity by a factor 10 beyond its original design value. The complex upgrade, which must be implemented with minimal disruption to LHC operations, demands careful study and will take a decade to achieve.

The HL-LHC relies on several innovative and challenging technologies, in particular: new superconducting dipole magnets with a field of 11 T; highly compact and ultra-precise superconducting "crab" cavities to rotate the beams at the collision points and thus compensate for the larger beam crossing angle; beam-separation and recombination superconducting dipole magnets; beam-focusing superconducting quadrupole magnets; and 80 m-long high-power superconducting links with zero energy dissipation.

These new LHC accelerator components will be mostly integrated at Point 1 and Point 5 of the ring where the two general-purpose detectors ATLAS and CMS are located (see diagram). The new infrastructure and services consist mainly of power transmission, electrical distribution, cooling, ventilation, cryogenics, power converters for superconducting magnets and inductive output tubes for superconducting RF cavities. To house these large elements, civil-engineering structures including buildings, shafts, caverns and underground galleries are required.

Design study complete

The definition of the civil engineering for the HL-LHC began in 2015. Last year, the completion of a concept study allowed CERN to issue a call for tender for two civil-engineering consultant contracts, which were adjudicated in June 2016. These consultants are in charge of the preliminary, tender and construction design phases of the civil-engineering work, in addition to managing the construction and defect-liability phase. At Point 1, which is located in Switzerland just across from the main CERN entrance, the consultant contract involves a consortium of three companies: SETEC TPI (France), which is the consortium leader, together with CSD Engineers (Switzerland) and Rocksoil (Italy). A similar consortium has been appointed at Point 5, in France. Here, the consultant contract is shared between consortium-leader Lombardi (Switzerland), Artelia (France) and Pini Swiss (Switzerland). In November 2016, the two consultant consortia completed the preliminary design phase including cost and construction-schedule estimates for the civil-engineering work.

In parallel with the preliminary design, and with the help of external architects, CERN has submitted building-permit applications to the Swiss and French authorities with a view to start construction work by mid-2018. CERN has also performed geotechnical investigations to better understand the underground conditions (which consist of glacial moraines overlying a local type of soft rock called molasse), and has placed a contract with independent engineers ARUP (UK) and Geoconsult (Austria). These companies will confirm that the consultant designs have been performed with the appropriate skill, care and diligence in accordance with applicable standards. In addition, a panel comprising lawyers, architects and civil engineers is in place to resolve any disputes between parties.

At ground level, the HL-LHC civil engineering consists of five buildings at each of the two LHC points, technical galleries, access roads, concrete slabs and landscaping. At each point, the total surface corresponds to about 20,000 m^2 including 3300 m^2 of buildings. A cluster of three buildings is located at the head of the shaft and will house the helium-refrigerator cold box (SD building, see images above), water-cooling and ventilation units (SU building) and also the main electrical distribution for high and low voltage (SE building). Completing the inventory at each point are two stand-alone buildings that will house the primary water-cooling towers (SF building) and the warm compressor station of the helium refrigerator (SHM building). Buildings housing noisy equipment (SU, SF, SHM) will be constructed with noise-insulating concrete walls and roofs.

In terms of underground structures, the civil-engineering work consists of a shaft, a service cavern, galleries and vertical cores (see image above left). The total volume to be excavated is around 50,000 m^3 per point. The PM shaft (measuring 9.7 m in diameter and 70–80 m deep) will house a secured access lift and staircase as well as the associated services. The service cavern (US/UW, measuring 16 m in diameter and 45 m long) will house cooling and ventilation units, a cryogenic box, an electrical safe room and electrical transformers. The UR gallery (5.8 m diameter, 300 m long) will house the power converters and electrical feed boxes for the superconducting magnets as well as cryogenic and service distribution. Two transverse UA galleries (6.2 m diameter, 50 m long) will house the RF equipment for the powering and controls of the superconducting crab cavities. At the end of the UA galleries, evacuation galleries (UPR) are required for personnel emergency exits. Two transversal UL galleries (3 m diameter, 40 m long) will house the superconducting links to power the magnets and cryogenic distribution system. Finally, the HL-LHC underground galleries are connected to the LHC tunnel via 16 vertical cores measuring 1 m in diameter and approximately 7 m long.

Next milestone

The next important milestone will be the adjudication in March 2018 of the two contracts (one per point) for the civil-engineering construction work. In December 2016, CERN launched a market survey for the construction tender, which will be followed by invitations to tender to qualified firms by June 2017. The main excavation work, which may generate harmful vibrations for the LHC accelerator performance, must be performed during the second long shutdown of the LHC accelerator scheduled for 2019–2020. Handover of the final building is scheduled by the end of 2022, while the vertical cores connecting the HL-LHC galleries to the LHC tunnel will be constructed at the start of the third LHC long shutdown beginning in 2024.

Realising the HL-LHC is a major challenge that involves more than 25 institutes from 12 countries, and in addition to civil-engineering work it demands several cutting-edge magnet and other accelerator technologies. The project is the highest priority in the European Strategy for Particle Physics, and will ensure a rich physics programme at the high-energy frontier into the 2030s.

Résumé

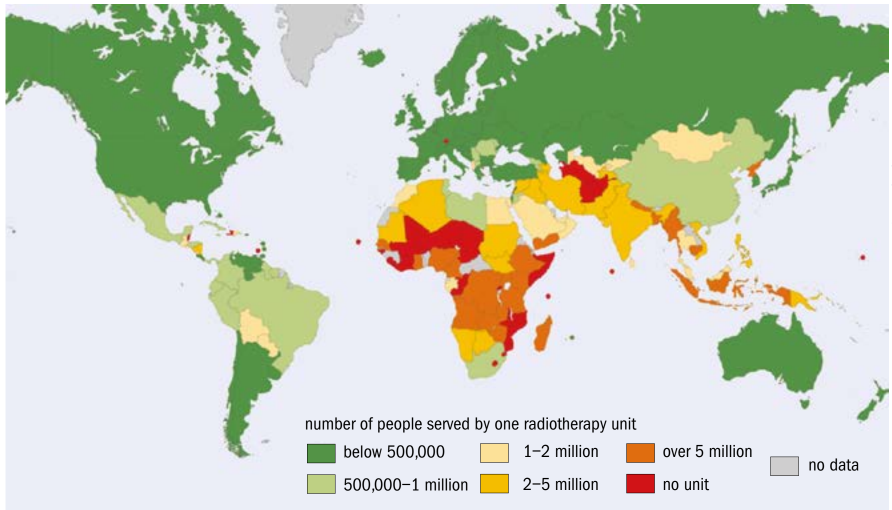
Cap sous terre

Le HL-LHC sera composé de plusieurs technologies et aimants innovants, et ces nouveaux éléments de l'accélérateur auront besoin de services supplémentaires tels que transmission de courant, distribution électrique, refroidissement, ventilation et cryogénie. Afin d'héberger les nouvelles infrastructures et les nouveaux éléments, des structures de génie civil, notamment des bâtiments, des puits, des cavernes et des galeries souterraines sont nécessaires. L'achèvement, l'année passée, de la phase de conception préliminaire du HL-LHC a permis le commencement des travaux de génie civil, et des contrats avec des entreprises externes vont à présent être conclus.

Laurent Jean Tavian and **Pieter Mattelaer**, CERN.

Developing medical linacs for challenging regions

A workshop held at CERN late last year saw physicists, oncologists and industry experts define the design characteristics of a novel linear accelerator that will make radiotherapy more readily available in lower-resourced countries.



IAEA, AGaRT: cancer.iaea.org/agart.asp

Map of the world showing access to radiotherapy treatment centres. There is a shortfall of more than 5000 radiotherapy machines in low-to-middle income countries, with patients in some countries in Africa and Asia having almost no access to radiation therapy, much less modern technology and expertise (data from IAEA-DIRAC database, 03/2012).

The annual global incidence of cancer is expected to rise from 15 million cases in 2015 to as many as 25 million cases in 2035. Of these, it is estimated that 65–70% will occur in low-and middle-income countries (LMICs) where there is a severe shortfall in radiation treatment capacity. The growing burden of cancer and other non-communicable diseases in these countries has been recognised by the United Nations General Assembly and the World Health Organization.

Radiation therapy is an essential component of effective cancer control, and approximately half of all cancer patients – regardless of geographic location – would benefit from such treatment. The vast majority of modern radiotherapy facilities rely on linear accelerators (linacs) to accelerate electrons, which are either used directly to treat superficial tumours or are directed at targets such as tungsten to produce X-rays for treating deep-seated tumours.

Electron linacs were first used clinically in the 1950s, in the UK and the US. Since then, great advances in photon treatment have been made. These are due to improved imaging, real-time beam shaping and intensity modulation of the beam with multileaf collimators, and knowledge of the radiation doses to kill tumours alone and in combination with drugs. In addition, the use of particle beams means that radiotherapy directly benefits from knowledge and technology gained in high-energy-physics research.

Meeting global demand

In September 2015, the Global Task Force on Radiotherapy for Cancer Control (GTFRCC) released a comprehensive study of the global demand for radiation therapy. It highlighted the inadequacy of current equipment coverage (image above) and the resources required, as well as the costs and economic and societal benefits of improving coverage.

Limiting factors to the development and implementation of radiotherapy in lower-resourced nations include the cost of equipment and infrastructure, and the shortage of trained personnel to properly calibrate and maintain the equipment and to deliver high-quality treatment. The GTFRCC report estimated that as many as 12,600 megavolt-class treatment machines will be needed to meet radiotherapy demands in LMICs by 2035. Based on current staffing models, it was estimated that an additional 30,000 radiation oncologists, more than 22,000 medical physicists and almost ▷

CERN workshop initiates discussions for novel medical linacs

On 7–8 November 2016, CERN hosted a first-of-its-kind workshop to discuss the design characteristics of radiotherapy linacs for low- and middle-income countries (LMICs). Around 75 participants from 15 countries addressed: the role of radiotherapy in treating cancer in challenging environments and the related security of medical radiological materials, especially ^{60}Co and ^{137}Cs; the design requirements of linear accelerators and related technologies for use in challenging environments; the education and training of a sustainable workforce needed to utilise novel radiation treatment systems; and the cost and financing of the project. Leading experts were invited from international organisations, government agencies, research institutes, universities and hospitals, and companies that produce equipment for conventional X-ray and particle therapy.

80,000 radiation technologists will be required.

Approximately three years ago, with the aim of making cancer treatments accessible to underserved populations, initial discussions took place between CERN and representatives of the US National Cancer Institute and an emerging non-government organisation, the International Cancer Expert Corps (ICEC), whose aim is to help LMICs establish in-country cancer-care expertise. The focus of discussions was on an "out-of-the-box" concept for global health, specifically the design of a novel, possibly modular, linear accelerator for use in challenging environments (defined as those in which the general infrastructure is poor or lacking, where power outages and water-supply fluctuations can occur, and where climatic conditions might be harsh). Following further activities, CERN hosted a workshop in November 2016 convened by the ICEC, which brought together invited experts from many disciplines including industry (see panel above).

In addition to improving the quality of care for cancer patients globally, linac-based radiotherapy systems also reduce the reliance on less expensive and simpler systems that provide treatment with photons from radionuclide sources such as ^{60}Co and ^{137}Cs. While some of the ^{60}Co units have multileaf collimators for improved beam delivery, they do not have the advanced features of modern linacs. Eliminating radionuclides also reduces the risk of malicious use of medical radioactive materials (see panel opposite).

Design characteristics

It is important that the newly designed linac retains the advanced capability of the machines now in use, and that through software advances, resource sharing and sustainable partnerships, the treatments in LMICs are of comparable quality to those in upper-income countries. This not only avoids substandard care but is also an incentive for experts to go to and remain in LMICs.

The ideal radiation-therapy treatment system for LMICs is thought to be as modular as possible, so that it can be easily shipped, assembled *in situ*, repaired and upgraded as local expertise in patient treatment develops. Another critical issue concerns the sustainability of treatment systems after installation. To minimise the need for local specialised technical staff to maintain and promptly repair facilities, procedures and economic models need to be developed to ensure regional technical expertise and also a regional supply of standard spare parts and simpler (modular) replacement procedures. Difficulties due to remoteness and poor communication also need to be considered.

There are several design considerations when developing a linear accelerator for operation in challenging environments. In addition to ease of operation, repair and upgradability, key factors include reliability, self-diagnostics, insensitivity to power interruptions, low power requirements and reduced heat production. To achieve most of these design considerations relatively quickly requires a system based on current hardware technology and software that fully exploits automation. The latter should include auto-planning and operator monitoring and training, even to the point of having a treatment system that depends on limited on-site human involvement, to allow high-quality treatment to be delivered by an on-site team with less technical expertise.

More than 22,000 medical physicists and almost 80,000 radiation technologists will be required.

Current technology can be upgraded with software upgrades, but generally it requires the purchase of an entire new unit to substantially improve technology – often costing many millions of dollars. A modular design that allows major upgrades of components on the same base unit could be much less expensive. Major savings would also result from developing new advanced software to expand the capability of the hardware.

Participants in the CERN workshop agreed that we need to develop a treatment machine that delivers state-of-the-art radiation therapy, rather than to develop a sub-standard linac in terms of the quality of the treatment it could deliver. The latter approach would not only provide lower-quality treatment but would be a disincentive for recruitment and retention of high-quality staff. As used in virtually all industries, the user interface should be developed through interaction with the users. Improved hardware such as a power generator in conjunction with energy management should also be provided to control electrical network fluctuations.

The task ahead

Experience from past and current radiation-therapy initiatives suggests that successful radiotherapy programmes require secure local resources, adequate planning, local commitment and political stability. To make a highly functional radiotherapy treatment system available in the near-term, one could upgrade one or more existing linear accelerators with software optimisations. The design and development of a truly novel radiation treatment system, on the other hand, will require a task force to refine the design criteria and then begin development and production.

Following the November workshop, an oversight committee and three task forces have been established. A technology task force will focus on systems solutions and novel technology for a series of radiation-treatment systems that incorporate intelligent software and are modular, rugged and easily operated yet sufficiently sophisticated to also benefit therapy in high-income countries. A second task force will identify education and training requirements for the novel treatment systems, in addition to evaluating the impact of evolving treatment techniques, changes in cancer incidence and the population mix. Finally, a global connectivity and fundraising task force will develop strategies for securing financial support in client countries as well as from governmental, academic and philanthropic organisations and individuals.

The overall aim of this ambitious project is to make excellent near-term and long-term radiation treatment systems, including staffing and physical infrastructure, available for the treatment of cancer patients in LMICs and other geographically underserved regions in the next 5–10 years. The high-energy physics community's broad expertise in global networking, technology innovation and open-source knowledge for the benefits of health are essential to the progress of this ambitious effort. It is anticipated that an update meeting will take place at the International Conference on Advances in Radiation Oncology (ICARO2) to be held in Vienna in June 2017.

● Further reading

M Pomper *et al.* 2016 *Treatment, Not Terror: Strategies to Enhance External Beam Cancer Therapy in Developing Countries While Permanently Reducing the Risk of Radiological Terrorism* (report) www.stanleyfoundation.org/publications/report/TreatmentNotTerror212.pdf.
International Cancer Expert Corps www.iceccancer.org.
R Atun *et al.* 2015 *Lancet Oncol.* **16** 1153.

Treatment, not terror

With the rise in global terrorism comes the threat of the use of un- or poorly secured radioactive sources that would have enormous health, economic and political consequences. This includes medical sources such as ^{60}Co that are generally not highly protected, many of which are located in relatively under-resourced regions. Interest in developing alternative technologies has brought together medical practitioners who currently use these sources, governmental and global agencies whose mission includes the security of radiological and nuclear material, and organisations dedicated to the non-proliferation of nuclear weapons.

This confluence of expertise resulted in meetings in Brazil and South Africa in 2016, with the realisation that simply removing ^{60}Co would leave people in many regions without cancer care. Removing dangerous sources while establishing a better cancer-care environment would require education, training, mentorship and partnerships to use more complex linear-accelerator-based radiotherapy systems. The austerity of the environment is a challenge that requires new thinking, however.

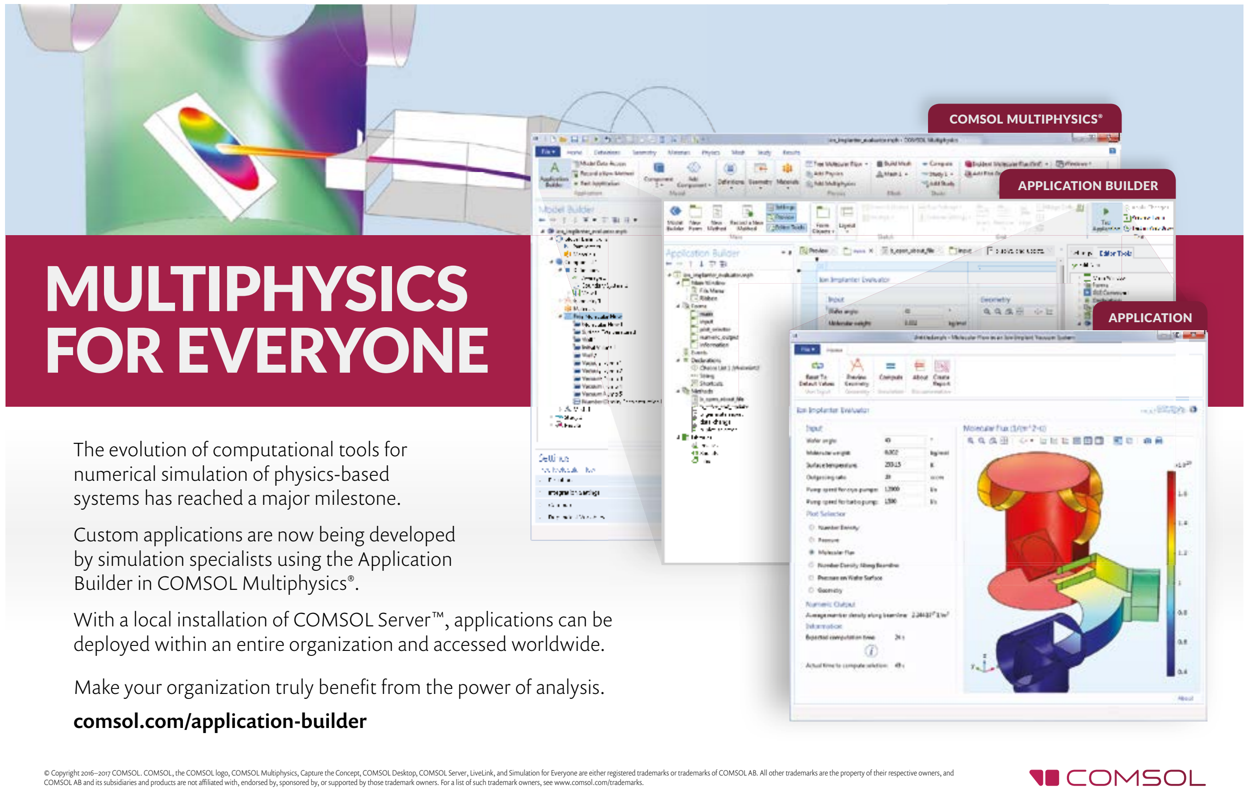
The ability to offer a state-of-the-art non-isotopic radiation treatment system for challenging environments was emphasised by the Office of Radiological Security of the US National Nuclear Security Administration, which is responsible for reducing the global reliance on radioactive sources as well as protecting those sources from unauthorised access. The benefit of replacing ^{60}Co radiation treatment units with linear accelerators from the point of view of decreasing the risk of malicious use of ^{60}Co by non-state (terrorist) actors was also emphasised in a report from the Center for Nonproliferation Studies that offered the new paradigm "treatment, not terror".

Résumé

Des linacs médicaux pour des régions défavorisées

Il manque actuellement plus de 5 000 machines de radiothérapie dans les pays en développement, et certains pays d'Afrique et d'Asie n'ont pratiquement aucun accès à cette thérapie. Un atelier réunissant des physiciens, des oncologues et des experts de l'industrie a été organisé au CERN fin 2016, dans le but d'imaginer les caractéristiques d'un accélérateur linéaire novateur capable de faciliter l'accès à ce traitement crucial contre le cancer dans les pays les plus défavorisés. Les compétences étendues du CERN et de la communauté des physiciens dans les domaines de la physique des hautes énergies, du réseautage au niveau mondial et de l'innovation sont essentielles pour faire avancer cet ambitieux projet.

David Pistenmaa and **Norman Coleman**, International Cancer Expert Corps, Inc.,and **Manjit Dosanjh**, CERN.



L Baudis

Testing WIMPs to the limit

A surface building at Gran Sasso National Laboratory in Italy, which hosts a network of caverns shielded from cosmic radiation.

The DARWIN observatory proposed to be built at Gran Sasso in the mid-2020s promises to be the ultimate dark-matter detector, probing the WIMP paradigm to its limit.

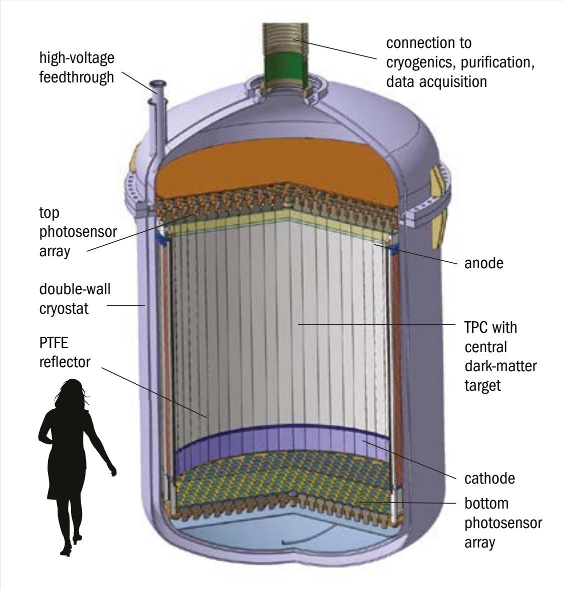
Dark matter is one of the greatest mysteries of our cosmos. More than 80 years after its postulation in modern form by the Swiss–American astronomer Fritz Zwicky, the existence of a new unseen form of matter in our universe is established beyond doubt. Dark matter is not just the gravitational glue that holds together galaxies, galaxy clusters and structures on the largest cosmological scales. Over the past few decades it has become clear that dark matter is also vital to explain the observed fluctuations in cosmic-microwave-background radiation and the growth of structures that began from these primordial density fluctuations in the early universe. Yet despite overwhelming evidence, its existence is inferred only indirectly via its gravitational pull on luminous matter. As of today, we lack the answer to the most fundamental questions: what is dark matter made of and what is its true nature?

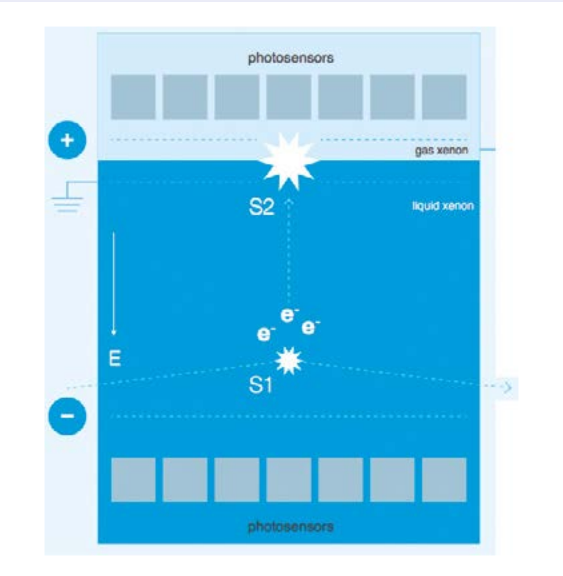
DARWIN, the ultimate dark-matter detector using the noble element xenon in liquid form, will be in a unique position to address these fundamental questions. Currently in the design and R&D phase, DARWIN will be constructed at the Gran Sasso National Laboratory (LNGS) in Italy and is scheduled to carry out its first physics runs from 2024. The DARWIN consortium is growing, and currently consists of about 150 scientists from 26 institutions in 11 countries.

Worldwide search

The particles described by the Standard Model of particle physics are unable to account for dark matter. Although neutrinos, the only elementary particles that do not interact with photons, would be ideal candidates, they are much too light and do not form the observed large-scale structures. Dark matter could, however, be made of new elementary particles that were born in the young and energetic universe. Such particles would carry no electric or colour charge, would be either stable or very long-lived and, similar to neutrinos, would interact only feebly (if at all) with known matter via new fundamental forces. Theories beyond the Standard Model predict a wealth of viable dark-matter candidates. The most popular class has the generic name of weakly interactive massive particles (WIMPs), while a different class is axions, ▷

DARWIN scales LXe technology to new heights





The DARWIN observatory will operate a large amount (50 tonnes) of liquid xenon in a low-background cryostat surrounded by concentric shielding structures (diagram above). The heart of the experiment is the dual-phase TPC, containing 40 tonnes of instrumented xenon mass (diagram above right). The high density of liquid xenon (3 kg/l) results in a short radiation length and allows for a compact detector geometry with efficient self-shielding. A drift field of the order 0.5 kV cm^{-1} across the liquid target will cause the electrons to drift away from the interaction vertex towards the liquid–gas interface. Large field-shaping rings made from oxygen-free, high-conductivity copper will ensure the homogeneity of the field. The TPC will mostly be constructed from copper as a conductor and polytetrafluoroethylene as an insulator, with the latter being an efficient reflector for vacuum ultra-violet scintillation light. It will be housed in a double-walled cryostat, and all the detector materials will first be selected for ultra-low intrinsic radioactivity using dedicated, high-purity germanium (HPGe) detector screening facilities.

In the baseline scenario, the prompt and proportional scintillation signals will be recorded by two arrays of photomultiplier tubes (PMTs) installed above and below the xenon target. These will have a diameter of 3" or 4" and feature a very low intrinsic radioactivity, high quantum efficiency of 35% at 178 nm, a gain of around 5×10^6 and a very low dark count rate at –100 °C. Albeit a proven and reliable technology, PMTs are bulky, expensive and generate a significant fraction of the radioactive background in a dark-matter detector, especially concerning nuclear recoils produced by neutrons from (alpha, n) reactions. Several alternative light read-out schemes are thus being considered by the collaboration in small R&D set-ups. Among these are arrays of silicon photomultipliers (with a potential scheme where the TPC is fully surrounded by photosensors), gaseous photomultipliers and hybrid photosensors. A novel concept of liquid-hole multipliers could allow for charge and light read-out in a single-phase TPC, and potentially result in a significant improvement in light yield and thus a lower energy threshold.

or more generally axion-like particles (ALPs).

Worldwide, more than a dozen experiments are preparing to observe low-energy nuclear recoils induced by galactic WIMPs in ultra-sensitive, low-background detectors. Since the predicted WIMP masses and scattering cross-sections are model-dependent and essentially unknown, searches must cover a vast parameter space. Among the most promising detectors are those based on liquefied noble-gas targets such as liquid xenon (LXe) or liquid argon (LAr) – a well-established technology that can be scaled up to tonne-scale target masses and take data over periods lasting several years.

DARWIN, which will operate a multi-tonne liquid-xenon time projection chamber (TPC), follows in the footsteps of its predecessors XENON, ZEPLIN, LUX and PandaX. The technology employed by these experiments is very similar and, in addition, the entire XENON collaboration is now a part of the DARWIN collaboration. Since December 2016, an upgraded detector called XENON1T has been recording its first dark-matter data at LNGS using two tonnes of liquid xenon as the WIMP target (the total mass of xenon in the detector is 3.3 tonnes). It will probe WIMP–nucleon cross-sections down to as little as 1.6×10^{-47} cm^2 at a mass of 50 GeV/c^2 (for comparison, the scattering cross-section of low-energy ^{7}Be solar neutrinos on electrons is about 6×10^{-45} cm^2). A further planned upgrade called XENONnT with seven tonnes of LXe will increase the WIMP sensitivity by one order of magnitude.

The goals of DARWIN are even more ambitious, promising an unprecedented sensitivity of 2.5×10^{-49} cm^2 at a WIMP mass of 40 GeV/c^2. Such a reach would allow us to explore the entire experimentally accessible parameter space for WIMPs, to the point where the WIMP signal becomes indistinguishable from background processes from coherent neutrino-nucleus scattering events.

Rich physics programme

DARWIN will not only search for WIMP dark matter. Because of its ultra-low background level, it will be sensitive to additional, hypothetical particles that are expected to have non-vanishing couplings to electrons. These include solar axions, galactic ALPs and bosonic super-weakly interacting massive particles called superWIMPs, which have masses at the keV scale and are candidates for warm dark matter. It will also detect low-energy solar neutrinos produced by proton–proton fusion reactions in the Sun (so-called pp neutrinos) with high statistics, and therefore address one of the remaining observational challenges in the field of solar neutrinos: a precise comparison of the Sun's neutrino and photon luminosities. Capable of providing a statistical precision of less than one per cent on this comparison with just five years of data, the high-statistics measurement of the pp-neutrino flux would provide a stringent test of the solar model, as well as neutrino properties, because non-standard neutrino interactions could modify the survival probability of electron neutrinos at these low energies.

The DARWIN observatory will also observe coherent neutrino-nucleus interactions from ^{8}B solar neutrinos and be sensitive to neutrinos of all flavours from core-collapse supernovae: it would see about 800 events, or 20 events/tonne, from a supernova with 27 solar masses at a distance of 10 kpc, for example. By looking at the time evolution of the event rate from a nearby supernova, DARWIN could possibly even distinguish between different supernova models. Finally, DARWIN would search for the neutrinoless double beta ($0\nu\beta\beta$) decay of ^{136}Xe, which has a natural abundance of 8.9 per cent in xenon. The observation of this ultra-rare nuclear decay would directly prove that neutrinos are Majorana particles, and that lepton number is violated in nature (*CERN Courier* July/August 2016 p34).

One common feature of these exciting questions in contemporary particle and astroparticle physics is the exceedingly low expected interaction rates in the detector, corresponding to less than one event per tonne of target material and year. In addition, these searches – with the exception of the $0\nu\beta\beta$ decay – require an energy threshold that is as low as possible (a few keV), while the $0\nu\beta\beta$ decay, superWIMP and axion searches will profit from the very good energy resolution of the detector. A multi-tonne liquid-xenon observatory such as DARWIN can address the combination of an ultra-low background level, a low-energy threshold and a good energy resolution within a single, large, monolithic detector.

The WIMP landscape

The current best sensitivity to WIMP searches for masses above 6 GeV/c^2 is provided by detectors using LXe as a target, and the majority of existing (XENON1T, LUX, PandaX) and planned (LZ, XENONnT) LXe dark-matter detectors employ dual-phase TPCs (figure 1). These detectors maintain xenon at a constant temperature of about –100 °C and detect two distinct signals (the prompt scintillation light and the ionisation electrons) via arrays of photosensors operated in the liquid and vapour phase. The observation of both signals delivers information about the type of interaction and its energy, as well as the 3D position and timing of an event. WIMP collisions and coherent neutrino scatters will produce nuclear recoils, while pp neutrinos, axions, superWIMPs and double beta decays, along with the majority of background events, will cause electronic recoils. Fast neutrons from materials or induced through cosmic-ray muons will also give rise to nuclear recoils, but WIMPs and neutrinos will scatter only once in a given detector, while neutrons can scatter multiple times in large detectors such as DARWIN.

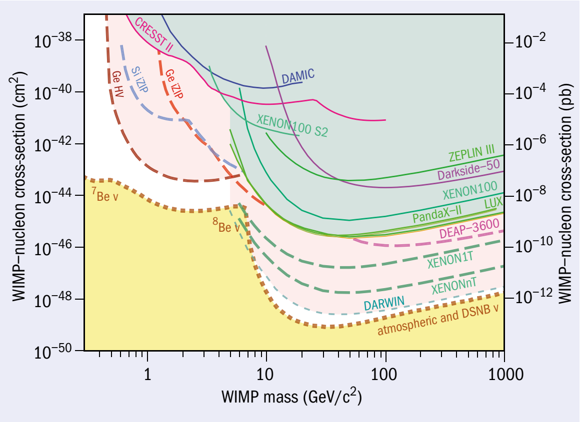


Fig. 1. The current experimental situation for spin-independent WIMP–nucleon interactions, with green showing excluded regions. Liquid-xenon and liquid-argon detectors (such as the operational DarkSide50, DEAP-3600, PandaX and XENON1T experiments) can probe WIMPs with masses above 6 GeV/c^2. At low WIMP masses, cryogenic detectors with phonon read-out, such as SuperCDMS, CRESST and EDELWEISS, and low-threshold Si-based detectors such as DAMIC, are leading the field.

Since the primary intent of DARWIN is to investigate dark-matter interactions, it is vital that background processes are understood. The observatory can exploit the full discovery potential of the liquefied xenon technique with a 40 tonne LXe TPC that allows all known sources of background to be considered. These stem from several sources: the residual radioactivity of detector-construction materials (γ radiation, neutrons); β decays of the anthropogenic ^{85}Kr present in the atmosphere due to nuclear fuel reprocessing, weapons tests and accidents such as that at Fukushima nuclear plant in Japan; and the progenies of ^{222}Rn in the LXe target. Two-neutrino double beta decays ($2\nu\beta\beta$) of ^{136}Xe and interactions of low-energy solar neutrinos (pp, ^{7}Be) are another source of background, as are higher-energy neutrino interactions with xenon nuclei in coherent neutrino-nucleus scattering.

In the standard WIMP-scattering scenario, the leading interactions between a dark-matter particle and a nucleon are due to two subtly different processes: spin-dependent couplings and isospin-conserving, spin-independent couplings. Since LXe contains nuclei with and without spin, DARWIN can probe both types of interactions. Assuming an exposure of ▷

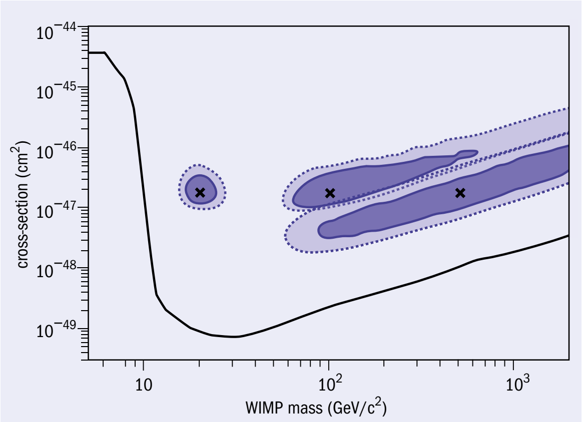


Fig. 2. Reconstructed parameters for three hypothetical particle masses (20, 100 and 500 GeV/c^2) and a cross-section of 2×10^{-47} cm^2 using realistic DARWIN detector parameters, backgrounds and astrophysical uncertainties.

200 tonnes × years (500 tonnes × years), a spin-independent WIMP sensitivity of 2.5×10^{-49} cm^2 (1.5×10^{-49} cm^2) can be reached at a WIMP mass of 40 GeV/c^2. For spin-dependent WIMP–neutron couplings and WIMP masses up to about 1 TeV, the searches conducted by DARWIN will be complementary to those of the LHC and High-Luminosity LHC at a centre-of-mass energy of 14 TeV. Natural xenon includes two isotopes with nonzero total nuclear angular momentum, ^{129}Xe and ^{131}Xe, at a combined abundance of about 50%. If the WIMP–nucleus interaction is indeed spin-dependent, DARWIN will also probe inelastic WIMP–nucleus scattering, where these two nuclei are excited into low-lying states at 40 keV and 80 keV, respectively, with subsequent prompt de-excitation. The discovery of such a signature would be a clear indication for an axial-vector coupling of WIMPs to nuclei.

Ultimate detector

Should dark-matter particles be discovered by one of the running (XENON1T, DEAP-3600) or near-future (LZ, XENONnT) detectors, DARWIN would be able to reconstruct the mass and scattering cross-section from the measured nuclear recoil spectra. With an exposure of 200 tonnes × years, 152, 224 and 60 events would be observed for the three WIMP masses, respectively (figure 2). DARWIN may therefore be the ultimate liquid-xenon dark-matter detector, capable of probing the WIMP paradigm and thus detect or exclude WIMPs with masses above 6 GeV/c^2, down to the extremely low cross-sections of 1.5×10^{-49} cm^2.

Should WIMPs not be observed in the DARWIN detector, the WIMP paradigm would be under very strong pressure. With its large, uniform target mass, low-energy threshold, and ultra-low background level, the observatory will also open up a unique opportunity for other rare event searches such as axions and other weakly interacting light particles. It will address open questions in neutrino physics, which is one of the most promising areas in which to search for physics beyond the Standard Model. At its lowest energies, the DARWIN detector will observe coherent neutrino-nucleus interactions from solar ^{8}B neutrinos, thus precisely testing the standard-solar-model flux prediction, and may detect neutrinos from galactic supernovae.

The DARWIN observatory was approved for an initial funding period, via ASPERA, in 2010. It is included in the European Roadmap for Astroparticle Physics and in various other programs, for example by the Swiss State Secretariat for Education, Research and Innovation and the Strategic Plan for Astroparticle Physics in the Netherlands. The current phase will culminate with a technical design report in 2019, followed by engineering studies in 2020 and 2021, with the construction at LNGS and first physics runs scheduled to start in 2022 and 2024, respectively. The experiment will operate for at least 10 years and may write a new chapter in the exciting story of dark matter.

● Further reading

www.darwin-observatory.org.
L Baudis 2016 *Annalen Phys.* DOI: 10.1002/andp.201500114.
L Baudis 2016 *J. Phys. G* DOI:10.1088/0954-3899/43/4/044001.
DARWIN Collaboration 2016 *JCAP* DOI:10.1088/1475-7516/2016/11/017.
T Marrodan *et al.* 2015 *J. Phys. G* DOI:10.1088/0954-3899/43/1/013001.

Résumé

Pousser les WIMP jusque dans leurs limites

L'observatoire DARWIN, dont l'activité doit commencer dans les années 2020 au laboratoire de Gran Sasso, promet d'être idéalement placé pour se pencher sur la nature de la matière noire. Il utilisera un élément noble, le xénon, sous sa forme liquide, pour détecter des WIMP (soit des particules massives interagissant faiblement), et aura une sensibilité sans précédent de $2{,}5 \times 10^{-49}$ cm^2 pour une masse des WIMP de 40 GeV/c^2. Cela permettra de tester le paradigme des WIMP jusque dans ses limites, ainsi que d'étudier d'autres questions fondamentales à propos des neutrinos et d'autres particules. Il est prévu que DARWIN, actuellement dans sa phase de conception et de R&D, réalise ses premières campagnes pour la physique à partir de 2024. Le groupement DARWIN s'agrandit, et comprend actuellement environ 150 scientifiques de 26 instituts, situés dans 11 pays.

Laura Baudis, University of Zurich, Switzerland.

AWARDS

French Physical Society presents awards


L Petzon/CNRS

L Petzon/CNRS

Marteen Boonekamp (left), François Gelis and Ubirajara van Kolck.

At a ceremony held on 19 December at IPN Orsay, the French Physical Society awarded the 2015 Prix Joliot Curie for experimental particle physics to Marteen Boonekamp of the Institut de recherche sur les lois fondamentales de l'Univers (IRFU) at Saclay. The prize, awarded every two years, recognised Boonekamp's contributions to the measurement of the W mass at the LHC's ATLAS experiment, of which he has been a member since 2001. The event also saw the French Physical Society present the Paul Langevin Prize, which recognises distinguished theorists and has not been awarded for the past few years. The winners of the 2015 Langevin Prize are François Gelis of the Institut de Physique Théorique Saclay, for his work on quantum field theory in the strong-field regime and its applications to the non-equilibrium evolution of quark–gluon plasma, and Ubirajara van Kolck of the Institut de Physique Nucléaire Orsay, for his formulation of effective field theories in nuclear physics.

Geneva physicists share Wolf Prize

The 2017 Wolf Prize in Physics has been awarded to Michel Mayor and Didier Queloz of the University of Geneva, for the discovery of an exoplanet orbiting a solar-type star. The pair made the discovery of "51 Pegasi b" in 1995 following continuous improvement of cross-correlation spectrographs over a period of 20 years. The prize citation says that the team led by Mayor and Queloz, who is also at the University of Cambridge in the UK, contributed to the discovery of more than 250 additional exoplanets and sparked a revolution in the theory of planetary systems.


ESO

BBVA Foundation

Exoplanet pioneers Michel Mayor (left) and Didier Queloz.

APPOINTMENTS

New LHCb spokesperson elected

Giovanni Passaleva of the Istituto Nazionale di Fisica Nucleare (INFN) Firenze, Italy, has been appointed as the next spokesperson of the LHCb experiment, taking over from Guy Wilkinson. Passaleva, who will become the new spokesperson in July, completed his PhD on the L3 experiment at LEP in 1995 and has been a member of the LHCb collaboration since 2000. His research interests include electroweak and flavour physics, as well as solid-state and gaseous tracking detectors, while his detector responsibilities include project leader of the LHCb muon system.


Giovanni Passaleva, currently co-ordinator for the LHCb upgrade.

EVENTS

DG speaks on open science

On 20 January, CERN Director-General Fabiola Gianotti took part in a panel discussion at the 2017 World Economic Forum in Davos, at which delegates addressed the top issues on the global science agenda. Gianotti reinforced the importance of fundamental research in driving technology and as a force for peaceful collaboration, and emphasised the need for open science. "Scientists have made good progress over the last years to engage the public, but we have to do more to reach out to people at all levels using the tools we have," she said. "Knowledge belongs to mankind, it does not belong to the scientists."


World Economic Forum/C McCrickard

Fabiola Gianotti speaking at the 2017 World Economic Forum in Davos.

ANNIVERSARY

Celebrating 50 years of neutron science at ILL

On 19 January, the Institut Laue-Langevin (ILL) in Grenoble marked 50 years of providing beams of neutrons for scientific users across a range of disciplines. The ILL was founded by the governments of France and Germany in 1967 with the aim of creating an intense, continuous source of neutrons devoted exclusively to civil fundamental research. Its first neutron beams were produced in 1971, and two years later the UK joined as the ILL's third associate member. Today, the institute has 10 scientific members: Spain, Switzerland, Austria, Italy, the Czech Republic, Sweden, Belgium, Slovakia, Denmark and Poland.

Research at the ILL covers fundamental physics to materials science and biology. The facility, which has an annual budget of around €100 million and almost 2000 user visits per year, has played a role in 21,000 scientific publications so far during its lifetime and is expected to operate well into the 2020s.

VISITS

Boris Johnson, secretary of state for foreign and commonwealth affairs, United Kingdom of Great Britain and Northern Ireland, visited CERN on 13 January, during which he took in the ATLAS control room and the LHC tunnel.


S Bennett/CERN


M Brice/CERN

Following the formal ascension of India as an associate Member State of CERN, Indian ambassador **Amandeep Singh Gill** visited CERN on 16 January. Here he is pictured with CERN Director-General Fabiola Gianotti holding the signed documents that will enable greater collaboration between India and CERN.

Bernard Bigot, director-general of the ITER Organisation, which is responsible for the international fusion experiment under construction in France, visited CERN on 16 January. Bigot, who has a PhD in chemistry and has held several senior scientific roles in the French government, toured both CMS and ATLAS in addition to the LHC tunnel. Here he is pictured signing the guestbook with Frédérick Bordry, CERN's director for accelerators and technology.

M Brice/CERN


M Brice/CERN


Chief scientist of Quebec in Canada, **Rémi Quirion**, visited CERN on 22 January, during which he toured the LHC tunnel and experiments. Quirion received a PhD in pharmacology from Université de Sherbrooke in 1980 and was previously a professor at McGill University and scientific director of the Douglas Hospital Research Centre.

CONFERENCES

DUNE collaboration meeting comes to CERN


M Brice/CERN

DUNE collaborators at CERN in January.

On 23–26 January, more than 230 members of the international Deep Underground Neutrino Experiment (DUNE) collaboration met at CERN to discuss the project's status and plans. A main focus of the meeting was to coordinate the assembly of prototype modules for the vast DUNE detector, which are being constructed in a new facility on the CERN site (see p18).

DUNE will comprise four detector modules with a total of 68,000 tonnes of liquid argon to detect neutrinos and look for rare subatomic phenomena such as proton decay. It will be situated 1.5 km underground at Sanford Underground Research Facility (SURF) in South Dakota, US. The experiment will be the target for intense beams of neutrinos and antineutrinos produced by a new facility to be built at Fermilab 1300 km away, and will address specific puzzles such as the neutrino mass hierarchy and CP violation in the neutrino sector.

CERN is playing a significant role in the DUNE programme via its recently established neutrino platform (*CERN Courier* July/August 2016 p21). A collaboration agreement was signed between CERN and the US in December 2015, in which CERN committed to the construction of prototype DUNE detectors and the delivery of one cryostat for the experiment in the US. Two large "protoDUNE" detectors are now taking shape in a new building in the north area of the CERN site.

DUNE aims to be for the neutrino what the LHC is for the Higgs boson, and enormous progress has been made in the past two years. Formed in early 2015, the collaboration now comprises 945 scientists and engineers from 161 institutions in 30 nations and is still growing, with about 60% of the collaborating institutions located outside the US. In September 2016, the US Department of Energy approved the excavation of the first caverns for DUNE, with preparatory work expected to begin at SURF this summer. A small, $3 \times 1 \times 1$ m^3 dual-phase demonstrator module constructed at CERN is also ready for filling and operation.

One of the highlights of the CERN meeting was a tour of the construction site for the large protoDUNE detectors. The vessel for the cryostat of the $6 \times 6 \times 6$ m^3 single-phase liquid-argon prototype module is almost complete, and the construction of an identical cryostat for a dual-phase detector will start soon. Preparing for the installation of liquid-argon time-projection-chamber (TPC) detector components, which will start this summer, was one of the main focuses of the meeting. Both single- and dual-phase protoDUNE detectors are scheduled to be operational and take data with the tertiary charged-particle beam from the Super Proton Synchrotron in 2018.

The DUNE collaboration is also starting to prepare a Technical Design Report (TDR) for the large underground detectors at SURF, and is working on the conceptual design for the DUNE near detector that will be placed about 55 m underground at the Fermilab site to measure neutrino interactions close to the source before the neutrinos start to oscillate.

Discussions about the responsibilities for building the vast number of detector components for the DUNE far detectors have begun, and additional scientists and institutions are welcome to join the collaboration. The goal is to finish the TDR for review in 2019 and to begin the construction of the far-detector components in 2021, with the first detector modules at SURF operational in 2024.

Daresbury accelerator workshop focuses on electron–positron factories


Cockcroft Institute

Participants of eeFACT2016 on the Daresbury campus.

From 24 to 27 October 2016, accelerator experts from around the world gathered in Daresbury, UK, to discuss the status, challenges and future of circular high-luminosity electron-positron factories. Organised under ICFA and co-sponsored by the EuCARD-2 accelerator network, the "eeFACT2016" workshop attracted 75 participants from China, France, Germany, Italy, Japan, Russia, Switzerland, the UK and the US.

Circular colliders have been a frontier technology of particle physics for half a century, providing more than a factor 10 increase in luminosity every 10 years. Several lower-energy factories are in operation: BEPC-II at IHEP Beijing, DAFNE at INFN Frascati and VEPP-2000 at BINP Novosibirsk. The SuperKEKB facility currently under commission in Japan (*CERN Courier* September p32) will mark the next step up in luminosity. Among other future projects, a super-charm-tau factory is being developed in Russia, while two ambitious high-energy circular Higgs-Z-W (and top) factories are being designed: the Circular Electron Positron Collider (CEPC) in China and the electron-positron version of the Future Circular Collider (FCC) at CERN.

Despite 50 years of experience and development of the e^+e^- landscape, in the past couple of years several game-changing schemes have been introduced, such as colliding beams with a crab waist, large Piwinski angle and extremely low emittance. The crab-waist concept has already demonstrated its great merits at DAFNE. Other novel concepts include: the use of a double ring or partial double ring; magnet tapering; top-up injection; cost-effective two-in-one magnets; ultra-low beta function; "virtual crab waist"; and asymmetric interaction-region optics. Upcoming colliders like SuperKEKB and the upgraded VEPP-2000 collider will test the limits of these new schemes. In parallel, much progress is being made in the design and operation of storage-ring light sources, which exhibit numerous topics of common interest with the collider world. There is also a powerful synergy between a future large circular high-energy lepton collider such as CEPC or FCC-ee and a subsequent hadron collider installed in the same tunnel, called SPPC and FCC-hh, respectively.

The projected performance of the future factories is further lifted by dramatic progress in accelerator technology such as superconducting radiofrequency (RF) systems, the efficiency of which have been revolutionised by novel production schemes such as nitrogen doping and thin-film Nb_3Sn coating. Several novel klystron concepts are on track to boost the power-conversion efficiency of RF power generators, which will make the next generation of colliders truly green facilities. With the performance of future factories being pushed so hard, subtleties that were unimportant in the past now arise – in particular concerning beam–beam effects.

Large future collider concepts such as FCC-ee and CEPC build on recent innovations and would greatly advance progress in fundamental physics at the precision frontier. At the same time new ideas for compact low-energy crab-waist colliders are emerging, which might offer attractive alternative paths for research and science.

Hadronic contributions to new-physics searches

The first international workshop on Hadronic Contributions to New Physics Searches (HC2NP 2016) was held on 25–30 September 2016 in Tenerife, Spain, inaugurating a new series aimed at hadronic effects that interfere in beyond-the-Standard-Model (SM) searches. A multidisciplinary group of 50 physicists attended the event to review four timely topics: muon g-2, flavour anomalies, sigma-terms in dark-matter searches, and the proton radius puzzle.

The anomalous magnetic moment of the muon (g-2) provides one of the most precise tests of the SM, and theory currently stands at 3.3 standard deviations from the experimental measurements. Updates on the new measurements starting in 2017 at Fermilab and J-PARC were presented, with prospects to reduce the current experimental uncertainties by a factor of four within the next few years. Several ways to improve the theoretical uncertainty, especially on the hadronic side, were discussed – including new lattice-QCD calculations of the vacuum polarization contribution – and prospects for new experimental measurements at BESIII were also reviewed.

Anomalies in weak flavour transitions in hadrons are a hot topic, especially the B-meson decay anomalies measured at LHCb and the tantalising hints of lepton-universality violation in the so-called RK and RD* ratios. These signals should be validated by other B-decay modes, which requires new lattice calculations of form factors. Since new physics might not constrain itself to one flavour sector, decays of other mesons such as pions, kaons and baryons are also being scrutinized.

Regarding dark matter, the sigma terms (nucleon form factors of fundamental interest) are one of the main uncertainties when interpreting direct searches. Old tensions in the values of these quantities persist, as seen in the mild discrepancy between the results of lattice QCD and those obtained using effective field theory or dispersive methods from experimental data. Recent developments in effective field theories now enable the subsequent bounds from the direct searches to be interpreted in the context of dark-matter searches at ATLAS and CMS.

Finally, HC2NP addressed the proton charge radius puzzle – the five-standard-deviation discrepancy between the value measured for muonic versus normal hydrogen (*CERN Courier* October 2016 p7). Results from electron–proton scattering have become controversial because different values of the radius are extracted from different fits to the same data, while lattice calculations of the proton charge radius so far do not provide the required accuracy. Recent chiral perturbation theory calculations of proton polarisability effects in muonic hydrogen show that this effect is relatively small, and new experiments on muonic deuterium and helium show that the same discrepancy exists for the deuterium but not the helium. With PSI due to perform a new experiment on the ground-state hyperfine splitting of muonic hydrogen, we require a factor 10 improvement in our understanding of proton-structure effects.


A Gutierrez & S Torres

Four hot topics relating to searches for BSM physics were discussed at HC2NP2016.

Given the success of the meeting, a new edition of HC2NP covering a selection of timely subtopics will be organised in Tenerife during 2018.

Quark confinement and the hadron spectrum

Some 400 theorists and experimentalists convened in Thessaloniki, Greece, from 29 August to 3 September 2016 for the 12th Quark Confinement and the Hadron Spectrum conference. Initiated in 1994, the series has become one of the most important and well attended forums in strong-interaction physics. The event (which this year included 40 plenary talks, 267 parallel talks and 33 posters) is organised in eight parallel sections: vacuum structure and confinement; emergent gauge fields and chiral fermions; light quarks; heavy quarks; deconfinement; QCD and new physics; nuclear and astroparticle physics; and strongly coupled theories. Two additional parallel sessions devoted to statistical methods and instrumentation were also included this year.


N Gulitskiy

Delegates at this year's Quark Confinement and the Hadron Spectrum conference.

The event brought together physicists working on approaches ranging from lattice field theory to higher-order perturbative and resummation methods; from phenomenology to experiments; from the mechanisms of confinement to deconfinement in heavy-ion physics; and from effective field theories of QCD to physics beyond the Standard Model. Only a brief summary of the wealth of results presented can be mentioned here.

Of particular interest was a talk exploring the connections between gravitational-wave results from LIGO and hadron physics: the gravitational-wave signature for neutron-star mergers depends strongly on the QCD equation of state (EOS) and different assumptions about the EOS lead to uncertainties on the merger time, wave amplitude, peak frequency and radiated energy. Fortunately, there are other ways of exploring the QCD EOS at high density, such as upcoming experiments at the new FAIR facility in Germany, RHIC in the US and NICA in Russia, which also complement studies of the low-density regime of the EOS with heavy-ion collisions at the LHC.

Several talks placed an emphasis on anomalies with respect to the Standard Model. The chiral anomaly in the background magnetic field of heavy-ion collisions, for example, has also been observed in condensed-matter physics in "Dirac semimetals". Other talks addressed flavour anomalies and whether they could be a signal of new physics or be described by standard QCD effects. The status of heavy-flavour production from protons to ions was presented and the quarkonium production mechanism was emphasised, including the production of charmonium-like exotics.

A number of talks were dedicated to physics on the scale of the nucleon rather than the nucleus, including new approaches to the parton distributions in the proton from lattice QCD, field theories and global analyses, incorporating results from JLab and the LHC. The status of the proton radius puzzle also generated lively discussions.

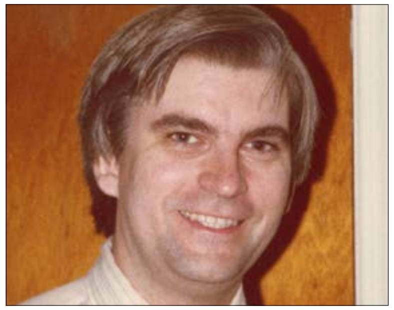
The conference was followed by a satellite workshop on new accelerator-based facilities that will provide precision measurements of confinement and deconfinement physics, demonstrating the health of the field.

OBITUARIES

Thomas Dombeck 1945–2016

Tom Dombeck, an innovative and versatile physicist and project manager, passed away in Kāne‘ohe, Hawaii, on 4 November 2016. His legacy includes many measurements in particle physics, the development of new techniques for the production of ultra-cold neutrons and substantial contributions to the management of several major scientific projects.

Tom received a BA in physics from Columbia University in 1967 and a PhD in particle physics from Northwestern University in 1972, and his career saw him hold prominent roles at numerous institutes. He was a research associate at Imperial College London from 1972 to 1974 and visiting scientist at Dubna in the former USSR in 1975. Following six years at the University of Maryland, from 1981 to 1988 Tom held various roles at Los Alamos National Laboratory (LANL) after which he spent a year working in the US Department of Energy in the office of the Superconducting Supercollider (SSC). Afterwards he became a staff physicist and ultimately deputy project manager for operations at the SSC laboratory in Texas, where he led the successful "string test". In 1994 he moved to a role as project manager for the Sloan Digital Sky Survey at the University of Chicago.



Tom Dombeck served as project manager for numerous activities including the SSC.

Tom was deputy head for the technical division at Fermilab from 1997 to 1999, and project manager for the Next Linear Collider project at Fermilab between 2000 and 2002. From 2003 to 2006 he was project manager for the Pan-STARRS telescope at the University of Hawaii and an affiliated graduate faculty member there until 2016. Tom began his scientific research with bubble chambers and was a key participant in the experiment that observed the first neutrino interaction in a hydrogen filled bubble chamber in 1970 at the ZGS at Argonne National Laboratory.

For many years he pursued measurements of the electric dipole moment (EDM) of the neutron and was also involved in the development of ultra-cold neutrons by Doppler shifting at pulsed sources. He proposed a new method for a neutron EDM measurement that involved Bragg scattering polarised neutrons from a silicon crystal and led an initial effort at the Missouri University Research Reactor, after which he initiated an experiment using the reactor at the NIST Center for Neutron Research.

While at LANL, Tom led a neutrino-oscillation search that involved constructing a new beamline and neutrino source at LAMPF and provided improved limits on muon-neutrino to electron-neutrino oscillations. He carried these fundamental physics interests and abilities to his later work as a highly effective scientific programme manager.

Tom was able to see the connections between disparate scientific areas and bring together new ideas and approaches that moved the field forwards. He could inspire people around him with his enthusiasm and kindness, and his wry sense of humour and wicked smile were trademarks that will long be remembered by his friends and colleagues. Tom was a devoted family man and is missed greatly by his wife Bonnie, his two children, Daniel and Heidi, and his four grandchildren.

● *Art McDonald, Michael Peters, Tom Bowles, Sam Werner, Thomas Wangler, Don Koetke and Nick Kaiser.*

Sidney Drell 1926–2016

Sidney David Drell, professor emeritus of theoretical physics at SLAC National Accelerator Laboratory, senior fellow at Stanford's Hoover Institution and a giant in the worlds of both academia and policy, died on 21 December 2016 at his home in Palo Alto, California. He was 90 years old.

Drell made immense contributions to his field, including uncovering a process that bears his name and working on national and international security. His legacy as a humanitarian includes his friendship and support of Soviet physicist and dissident Andrei Sakharov, who won the Nobel Peace Prize in 1975 for his opposition of the abuse of power in the Soviet Union. Drell was also known for his welcoming nature and genuine, albeit perhaps unwarranted, humility.

SLAC National Accelerator Laboratory

Sidney Drell, physicist and humanitarian in equal measure.

Drell's commitment to arms control spanned more than 50 years. He served on numerous panels advising US Congress, the intelligence community and military. He was an original member of JASON, a group of academic scientists created to advise the government on national security and defence issues, and from 1992 to 2001 he was a member of the President's Foreign Intelligence Advisory Board. He was also the co-founder of the Center for International Security and Cooperation at Stanford, and in 2006 he and former Secretary of State George Shultz began a programme at the Hoover Institution dedicated to developing practical steps towards ridding the world of nuclear weapons.

In 1974, Drell met Sakharov at a conference hosted by the Soviet Academy of Sciences and they quickly became friends. When Sakharov was internally exiled to Gorky from 1980 to 1986 following his criticism of the Soviet invasion of Afghanistan, Drell exchanged letters with him and called on Soviet leader Mikhail Gorbachev for his release. He also organised a petition to allow another Soviet physicist and dissident, Nohim Meiman, to emigrate to Israel, and obtained the signatures of 118 members of the US National Academy of Sciences.

Having graduated with a bachelor's degree from Princeton University in 1946, Drell earned a master's degree in 1947 and a PhD in physics in 1949 from the University of Illinois, Urbana-Champaign. He began at Stanford in 1950 as an instructor in physics, leaving to work as a researcher and assistant professor at the Massachusetts Institute of Technology and then returning to Stanford in 1956 as a professor of physics. He served as deputy director of SLAC from 1969 until his retirement from the lab in 1998.

Drell's research was in the fields of quantum electrodynamics and quantum chromodynamics. While at SLAC, he and research associate Tung-Mow Yan formulated the famous Drell–Yan Process, which has become an invaluable tool in particle physics.

His theoretical work was critical in setting SLAC on the course that it took. As head of the SLAC theory group, Drell brought in a host of younger theoretical physicists who began creating the current picture of the structure of matter. He played an important role in developing the justification for experiments and turning the results into what became the foundation of the Standard Model of particle physics.

For his research and lifetime of service to his country, Drell received many prestigious awards, including: the National Medal of Science; the Enrico Fermi Award; a fellowship from the MacArthur Foundation; the Heinz Award for contributions in public policy; the Rumford Medal from the American Academy of Arts and Sciences; and the National Intelligence Distinguished Service Medal. Drell was one of 10 scientists honoured as the founders of satellite reconnaissance as a space discipline by the US National Reconnaissance Office. He was elected to the National Academy of Sciences, the American Academy of Arts and Sciences and the American Philosophical Society, and was president of the American Physical Society in 1986.

Drell was also an accomplished violinist who played chamber music throughout his life.

He is survived by his wife, Harriet, and his children, Daniel, Virginia, Persis and Joanna. Persis Drell, a former director of SLAC who is also a physicist at Stanford and dean of the School of Engineering, will be the university's next provost.

● *Based, with permission, on the obituary published on the Stanford University website on 22 December 2016.*

M G K Menon 1928–2016

Mambillikalathil Govind Kumar Menon, a pioneer in particle physics and a distinguished statesman of science, passed away peacefully on 22 November at his home in New Delhi, India. He graduated with a bachelor of science from Jaswant College, Jodhpur, in 1946, and inspired by Chandrasekhara Venkata Raman, studied under the tutelage of spectroscopist Nanasaheb R Tawde before joining Cecil Powell's group at the University of Bristol, UK, in 1949.

ISRO-archives

M G K Menon, a driver of Indian science.

Menon's first important contribution was to establish the bosonic character of the pion through a study of fragments emerging from π-capture by light nuclei. He then focused his attention on the emerging field of K-meson physics. Along with his colleagues at Bristol, notably Peter Fowler, Cecil Powell and Cormac O'Ceallaigh, Menon discovered $K^+ \rightarrow \pi^+ \pi^0$ and $K^+ \rightarrow \pi^+ \pi^- \pi^+$ events in nuclear emulsion indicating parity non-conservation, (the $\tau - \theta$ puzzle). He also identified a sizeable collection of events showing the associated production of kaons and hyperons. In 1955 Menon joined the Tata Institute of Fundamental Research (TIFR), where he worked on cosmic-ray research programmes initiated by Homi Bhabha. Following Bhabha's death in an air crash over Mont Blanc in 1966, the responsibility of the directorship of TIFR fell squarely on his shoulders, along with the wide-ranging initiatives for national development that Bhabha had started. Notwithstanding these additional demands on his time, his focus on particle physics never wavered. He continued with his research, establishing a collaboration with Arnold W Wolfendale at the University of Durham, UK, and Saburo Miyake of Osaka City University, Japan, for the study of particle physics with detectors deployed deep underground; he detected events induced by cosmic-ray neutrino interactions; and he also launched a dedicated effort to test the early predictions of violation of baryon-number conservation leading to proton decay.

During his Bristol years, Menon established a close friendship with William O Lock, who had moved to CERN in 1959. This facilitated collaboration between TIFR and CERN, leading to the development of bubble-chamber techniques to study mesons produced in proton–antiproton collisions. These initial studies eventually led to highly successful collaborations between Indian researchers and the L3 experiment at LEP, and the CMS, ALICE and ATLAS experiments at the LHC.

Menon won several awards including the Cecil F Powell and C V Raman medals, and was elected to the three scientific academies in India. He was elected as a fellow of the Royal Society in 1970, and subsequently to the Pontifical Academy of Sciences, American Academy of Arts and Sciences, the Russian Academy of Sciences and as an honorary fellow of the Institute of Physics and the Institution of Electrical & Electronics Engineers. He also served two terms as president of the International Council of Scientific Unions, and stimulated its participation in policy issues, including climate change. Menon held a firm conviction that science can bring about technological development and societal progress, which motivated him to work with Abdus Salam in founding the Third World Academy of Sciences. He held several high positions in the Indian government, and thus contributed to the growth of science and technology in India.

Alongside his scientific achievements, M G K Menon was also very close to his wife Indumati and their two children Preeti and Anant Kumar. Our warmest thoughts go out to them and to innumerable others whose lives he touched in so many important ways.

● *Ramanath Cowsik.*

Helmut Oeschler 1945–2017


J Stroth

Helmut Oeschler was a member of ALICE.

Helmut Oeschler, an active member of the ALICE collaboration, passed away from heart failure on 3 January while working at his desk. Born in Southern Germany, he received his PhD from the University of Heidelberg in 1972 and held postdoc positions at the Niels Bohr Institute in Copenhagen, and in Strasbourg, Saclay and Orsay in France. From 1981 he was at the Institute for Nuclear Physics of TU Darmstadt. He held a Doctorate Honoris Causa from Dubna University, Russia, and in 2006 he received the Gay-Lussac-Humboldt prize.

Oeschler's physics interests concerned the dynamics of nuclear reactions over a broad energy range, from the Coulomb barrier to ultra-relativistic collisions. He was a driving force for building the kaon spectrometer at the GSI in Darmstadt, which made it possible to measure strange particles in collisions of heavy nuclei. From the late 1990s he was actively involved in addressing new aspects of equilibration in relativistic nuclear reactions.

Oeschler became a member of the ALICE collaboration at CERN in 2000 and made important contributions to the construction of the experiment. Together with his students, he was involved in developing track reconstruction software for measuring the production of charged particles in lead–lead collisions at the LHC. He also led the analysis efforts for the measurements of identified charged hadrons in the LHC's first proton–proton collisions. From 2010 to 2014 he led the ALICE editorial board, overseeing the publication of key results relating to quark-gluon matter at the highest energy densities. His deep involvement in the data analysis and interpretation continued unabated and he made important contributions to several research topics. Advising and working in close collaboration with students was a much loved component of Helmut's activity and was highly appreciated among the ALICE collaboration.

Helmut Oeschler was a frequent visitor of South Africa and served there on numerous international advisory committees. He was instrumental in helping the South African community develop the physics of heavy-ion collisions and collaboration with CERN.

With Helmut Oeschler we have lost an internationally renowned scientist and particular friend and colleague. His scientific contributions, especially on the production of strange particles in high-energy collisions, are important achievements.

● *His friends and colleagues.*

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National Institute for Theoretical Physics

Stellenbosch Node

Postdoctoral Fellow in Condensed Matter/Statistical Physics
(Two-year contract)

The Stellenbosch node of the South African National Institute for Theoretical Physics (NITheP) has a postdoctoral vacancy in the fields of Condensed Matter and Statistical Physics. The fellowship can be associated with any of the research groups and topics at that node.
The appointment will be made within the structure of Stellenbosch University on a two-year contract basis, with the possibility of renewal for one additional year.

Duties: Maintaining a vigorous research programme in Condensed Matter/Statistical Physics.
Requirements: A doctorate of high standing in a field relevant to the research activities at the NITheP Stellenbosch node. A developing research record and demonstrated research potential. PhD must have been obtained within the past five years.
Commencement of duties: 1 June 2017 or as soon as possible thereafter.
Closing date: Review of applications will begin on 1 March 2017 and continue until the fellowship has been awarded.
Value of fellowship: The value of the fellowship will be commensurate with experience and research profile.
Enquiries: Prof Frederik Scholtz on +27 21 808 3871 or at fgs@sun.ac.za.
Applications: Applications must include a cover letter, complete CV, publication list, description of present and future research interests, copies of relevant qualifications, as well as names and addresses/e-mails of at least 2 referees.
All documents must be submitted as a single PDF file to Mrs René Kotzé at renekotze@sun.ac.za.
Webpage: http://www.nithep.ac.za

**NITheP reserves the right not to make an appointment and to continue searching after the closing date. Only short-listed candidates will be contacted. Candidates not contacted by 1 April 2017 can assume that their applications were unsuccessful.*

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Please note that it is the applicants responsibility that all material, including letter of references, reach DESY before the deadline for the application to be considered.

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For further information and the application guideline please see https://www.fau.eu/university/careers-at-fau/professorships/.

Please submit your complete application documents (CV, list of publications excluding reprints, list of lectures and courses taught, copies of certificates and degrees, list of third-party funding) to the Dean of the Faculty of Sciences, FAU Erlangen-Nürnberg: Prof. Dr. Frank Duzaar, Universitätsstr. 40, D-91054 Erlangen, by **15.4.2017**. Please also send an electronic version to nat-dekanat@fau.de.

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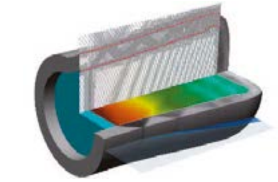

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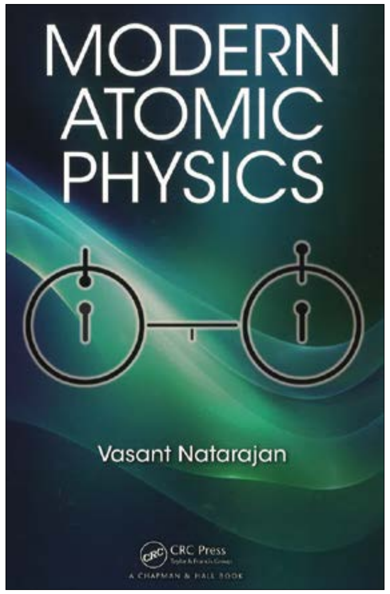
Compiled by Virginia Greco, CERN

Modern Atomic Physics

By Vasant Natarajan

CRC Press



This book collates information from various literature to provide students with a unified guide to contemporary developments in atomic physics. In just 400 pages it largely succeeds in achieving this aim.

The author is a professor of physics at the Indian Institute of Science in Bangalore. His research focuses on laser cooling and trapping of atoms, quantum optics, optical tweezers, quantum computation in ion traps, and tests of time-reversal symmetry using laser-cooled atoms. He received a PhD from the Massachusetts Institute of Technology under the supervision of David Pritchard, a leader in modern atomic physics and a mentor of two researchers – Eric Cornell and Wolfgang Ketterle – who went on to become Nobel laureates.

The book addresses the basis of atomic physics and state-of-the-art topics. It explains material clearly, although the arrangement of information is quite different to classical atomic-physics textbooks. This is clearly motivated by the importance of certain topics in modern quantum-optics theory and experiments. The physics content is often accompanied by the history behind concepts and by explanations of why things are named the way they are. Historical notes and personal anecdotes give the book a very appealing flair.

Chapter one covers different measurement systems and their merits, followed by universal units and fundamental constants, with a detailed explanation of which constants are truly fundamental. The next chapter is devoted to preliminary materials, starting with the harmonic oscillator and moving to concepts – namely coherent and squeezed states – that are important in quantum optics but not explicitly covered in some other books in the field. The chapter ends with a section on radiation, even including a description of the Casimir effect.

Chapter three is called Atoms. Alongside classical content such as energy levels of one-electron atoms, interactions with magnetic and electric fields, and atoms in oscillating fields, this chapter explains dressed atoms and also, unfortunately only briefly, includes a description of the permanent atomic electric dipole moment (EDM).

The following chapter is devoted to nuclear effects, the isotope shift and hyperfine structure. At this point it would have been nice to see some mention of the flourishing field of laser spectroscopy of radioactive nuclei, which exploits the two above effects to investigate the ground-state properties of nuclei far from the valley of stability.

Chapter five is about resonance, which is often scattered around in other books about atomic physics. Here, interestingly, nuclear magnetic resonance (NMR) plays a central role, and the chapter connects this topic very naturally to atomic physics. The chapter closes with a description of the density matrix formalism. After this comes a chapter devoted to interactions, including the electric dipole approximation, selection rules, transition rates and spontaneous emission. The last section is concerned with differences in saturation intensities by broadband and monochromatic radiation.

Multiphoton interactions are the topic of chapter seven, which is clearly motivated by their importance in modern quantum-optics laboratories. Two-photon absorption and de-excitation, Raman processes and the dressed atom description are all explained. Another crucial concept in modern quantum optics is coherence. Thus it is included as a full chapter, which includes coherence in a single atom and in ensembles of atoms, as well as coherent control in multilevel atoms. Spin echo appears as well, showing again how close the topics presented in the book are to NMR.

Chapter nine is devoted to lineshapes, which is clearly a subject relevant for modern atomic spectroscopists. Spectroscopy is the next chapter, which starts with alkali atoms – used extensively in laser cooling and Bose–Einstein condensates. The rest of the material is aimed at experimentalists. Uniquely for such a book, it includes a description of the key experimental tools, followed by Doppler-free techniques and nonlinear magneto-optic rotation.

The last chapter covers cooling and trapping, with so many relevant concepts already presented in the preceding chapters. The content includes different cooling approaches, principles of atom and ion traps, the cryptic and equally common Zeeman slower, and even more intriguing optical tweezers.

Each chapter ends with a problems section, in which the problems are often relevant to a real quantum-optics lab, for example concerning quantum defects, RF-induced magnetic transitions, Raman scattering cross-sections, quantum beats or the Voigt line profile. The problems are worked out in detail, allowing readers to follow how to arrive at the solution.

The appendices cover the standards and the frequency comb, which is one of the ingenious devices to come from the laboratory of Nobel laureate Theodor Hänsch and which can be now found in an ever-growing number of laser-spectroscopy and quantum-optics labs. Two other appendices are very different: they have a philosophical flair and deal with the nature of the photon and with Einstein as nature's detective.

The presented theoretical basis leads to state-of-the art experiments, especially related to ion and atom cooling and to Bose–Einstein condensates. The selection of topics is thus clearly tailored for experimentalists working in a quantum optics lab. One small criticism is that it would be good to read more about the EDM experiments and laser spectroscopy of radioactive ions, which are currently two very active fields. Readers interested in different classic subjects, like atomic collisions, should turn to other books such as Bransden and Joachain's *Physics of Atoms and Molecules*.

The level of the book makes it suitable for undergraduate level, but also for new graduate students. It can also serve as a quick reference for researchers, especially concerning the topics of general interest: metrology, what is a photon or how a

▷

frequency comb works, and how to achieve a Bose–Einstein condensate. Overall, the book is a very good guide to the topics relevant in modern atomic physics and its style makes it quite unique and personal.

- *Magdalena Kowalska, CERN.*

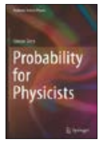
Books received

Probability for Physicists

By Simon Širca

Springer

Also available at the CERN bookshop



This book aims to deliver a concise, practical and intuitive introduction to probability and statistics for undergraduate and graduate students of physics and other natural sciences. The author attempts to provide a textbook in which mathematical complexity is reduced to a minimum, yet without sacrificing precision and clarity. To increase the appeal of the book for students, classic dice-throwing and coin-tossing examples are replaced or accompanied by real physics problems, all of which come with full solutions.

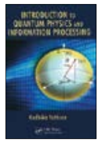
In the first part (chapters 1–6), the basics of probability and distributions are discussed. A second block of chapters is dedicated to statistics, specifically the determination of distribution parameters based on samples. More advanced topics follow, including Markov processes, the Monte Carlo method, stochastic population modelling, entropy and information.

The author also chooses to cover some subjects that, according to him, are disappearing from modern statistics courses. These include extreme-value distributions, the maximum-likelihood method and linear regressions using singular-value decomposition. A set of appendices concludes the volume.

Introduction to Quantum Physics and Information Processing

By Radhika Vathsan

CRC Press



An introduction to the novel and developing field of quantum information, this book aims to provide undergraduate and beginning graduate students with all of the basic concepts needed to understand more advanced books and current research publications in the field. No background in quantum physics is required because its essential principles are provided in the first part of the book.

After an introduction to the methods and notation of quantum mechanics, the authors explain a typical two-state system and how it is used to describe quantum information. The broader theoretical framework is also set out, starting with the rules of quantum mechanics and the language of algebra.

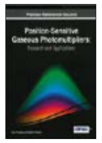
The book proceeds by showing how quantum properties are exploited to develop algorithms that prove more efficient in solving specific problems than their classical counterparts. Quantum computation, information content in qubits, cryptographic applications of quantum-information processing and quantum-error correction are some of the key topics covered in this book.

In addition to the many examples developed in the text, exercises are provided at the end of each chapter. References to more advanced material are also included.

Position-Sensitive Gaseous Photomultipliers: Research and Applications

By Tom Francke and Vladimir Peskov

IGI Global



Gaseous photomultipliers are gas-filled devices capable of detecting single photons (in the visible and UV spectrum) with a high position resolution. They are used in various research settings, in particular high-energy physics, and are among several types of contemporary single-photon detectors. This book provides a detailed comparison between photosensitive detectors based on different technologies, highlighting their advantages and disadvantages of them for diverse applications.

After describing the main principles underlying the conversion of photons to photoelectrons and the electron avalanche multiplication effect, the characteristics (and requirements) of position-sensitive gaseous photomultipliers are discussed. A long section of the book is then dedicated to describing and analysing the development of these detectors, which evolved from photomultipliers filled with photosensitive vapours to devices using liquid and then solid photocathodes. UV-sensitive photodetectors based on caesium iodide and caesium telluride, which are mainly used as Cherenkov-ring imaging detectors and are currently employed in the ALICE and COMPASS experiments at CERN, are presented in a dedicated chapter. The latest generation of gaseous photomultipliers, sensitive up to the visible region, are also discussed, as are alternative position-sensitive detectors.

The authors then focus on the Cherenkov light effect, its discovery and the way it has been used to identify particles. The introduction of ring imaging Cherenkov (RICH) detectors was a breakthrough and led to the application of these devices in various experiments, including the Cosmic AntiParticle Ring Imaging Cherenkov Experiment (CAPRICE) and the former CERN experiment Charge Parity violation at Low Energy Antiproton Ring (CP LEAR).

The latest generation of RICH detectors and applications of gaseous photomultipliers beyond RICH detectors are also discussed, completing the overview of the subject.

17 Big Bets for a Better World

By S Tackmann, K Kampmann and H Skovby (eds)

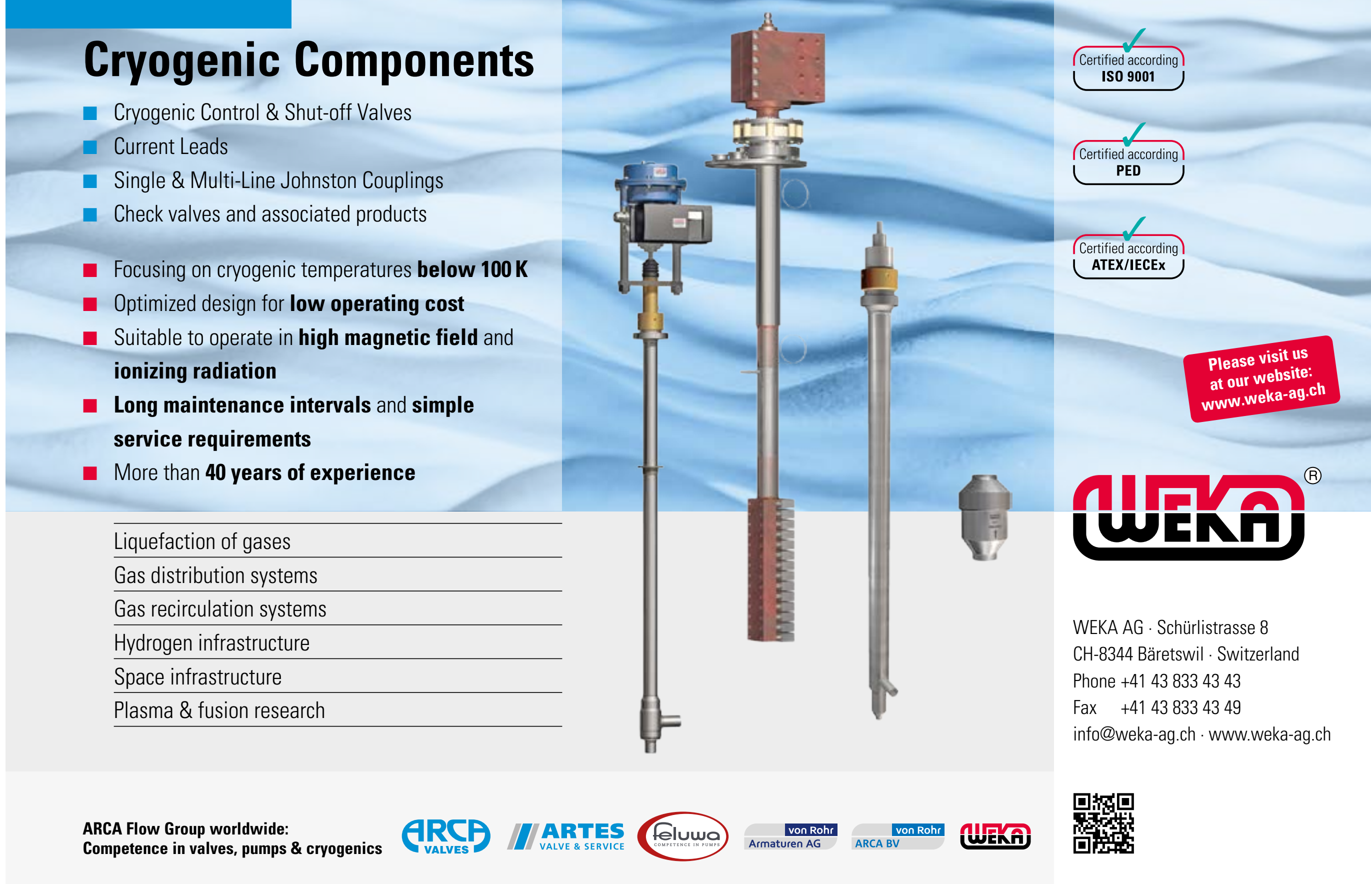
Forlaget Historika/Gad Publishers

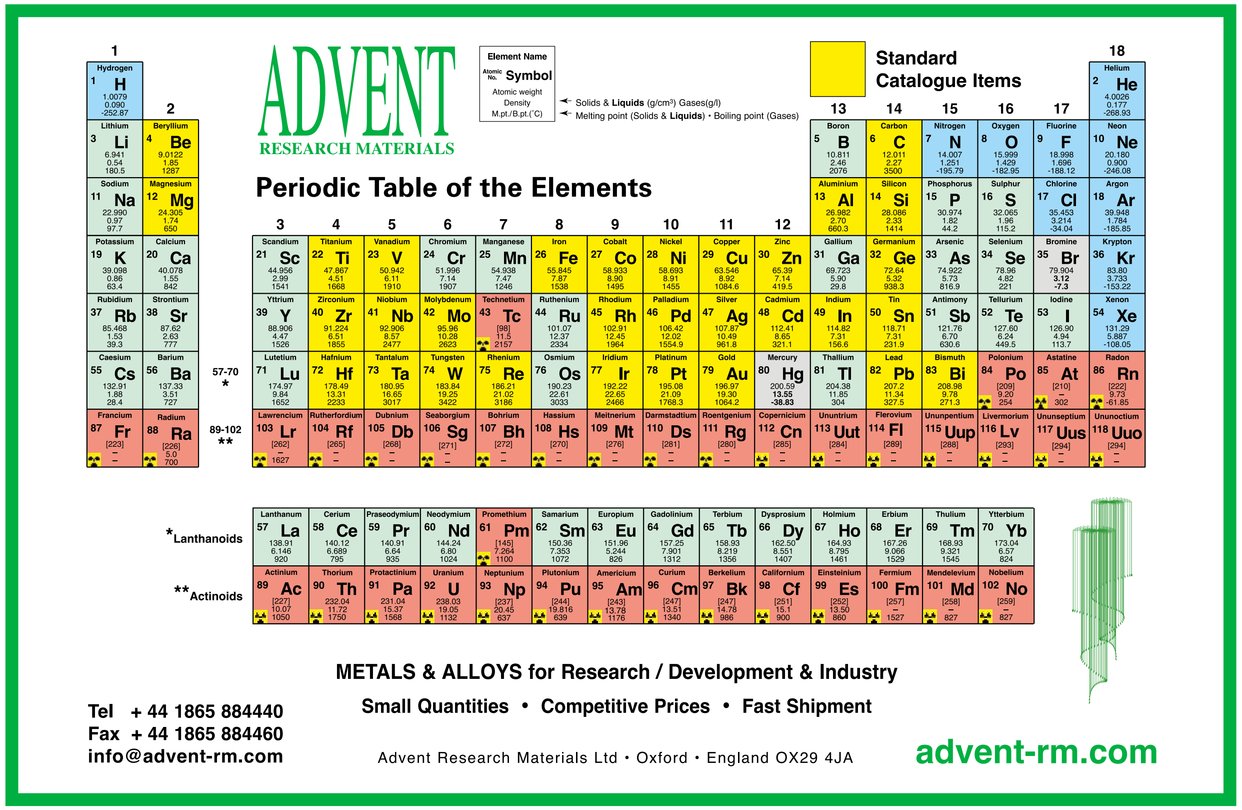
This book, which includes a contribution by CERN Director-General Fabiola Gianotti, presents 17 radical and game-changing ideas to help reach the 2030 Global Goals for Sustainable Development identified by the United Nations General Assembly.

Renowned and influential leaders propose innovative solutions for 17 "big bets" that the human race must face in the coming years. These experts in the environment, finance, food security, education and other relevant disciplines share their vision of the future and suggest new paths towards sustainability.

In the book, Gianotti replies to this call and shares her ideas about the importance of basic science and research in science, technology, engineering and maths (STEM) to underpin innovation, sustainable development and the improvement of global living conditions. After giving examples of breakthrough innovations in technology and medicine that came about from the pursuit of knowledge for its own sake, Gianotti contends that we need science and scientifically aware citizens to be able to tackle pressing issues, including drastic reduction of poverty and hunger, and the provision of clean and affordable energy. Finally, she proposes a plan to secure STEM education and funding for basic scientific research.

Published as part of the broader Big Bet Initiative to engage stakeholders around new and innovative ideas for global development, this book provides fresh points of view and credible solutions. It would appeal to readers who are interested in innovation and sustainability, as well as in the role of science in such a framework.





CERN Courier Archive: 1974

A look back to CERN Courier vol. 14, March 1974, compiled by Peggie Rimmer

SERPUKHOV

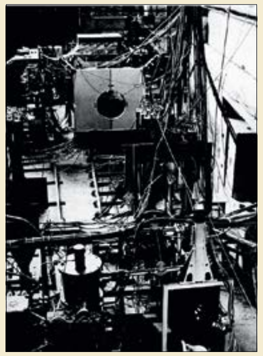
4th joint experiment

The 4th electronics experiment to be carried out under the agreement between CERN and the Institute for High Energy Physics at Serpukhov was installed at the IHEP 76 GeV proton synchrotron in October 1972. It has now gathered a large amount of data.

The experiment, involving physicists from Karlsruhe, Pisa, Serpukhov and Vienna, studies the charge exchange interaction $\pi^- + p \rightarrow n + \text{neutrals}$. The Karlsruhe and Pisa groups had examined this interaction at the CERN PS, detecting γ-rays and neutrons in coincidence. They were interested in carrying the study to higher energies, extending the mass range available for $\pi^0\pi^0$ and searching for higher mass resonances. A Serpukhov group, led by Yu D Prokoshkin, having completed an optical spark chamber experiment, was interested in gathering higher statistics on the interaction giving a neutron and a single neutral pion.

On the assumption of charge independence for the pion–nucleon interaction, the amplitude for charge exchange is determined by the difference between the amplitudes for elastic π^+p and π^-p scattering. The charge exchange reaction is also considered the most suitable for testing the Regge picture of high-energy interactions, central to many recent theoretical models. From both points of view, the high statistical and systematic accuracy expected in the new experiment is essential.

● Compiled from texts on pp83–84.



The Serpukhov experiment. In the foreground is the hydrogen target which is bombarded by a negative pion beam. Hidden in the concrete blocks on the right is the neutron detector. In the rear is the online gamma detector.

VILLIGEN

First pions at SIN

Protons were accelerated to full energy in the ring cyclotron of the Swiss Institute for Nuclear Research, SIN, for the first time on 18 January. A 590 MeV beam has been extracted and pions have been detected from the first target.

During the coming two months, another pion beam will be installed and three experiments around the first target will be made ready. By midsummer, the area around the second target will become operational together with two more pion beams and the neutron time-of-flight path. Muons from a superconducting solenoid are expected later in the summer and polarised protons by the autumn.

With this "meson factory", Professor W Blaser and his team have added a very important facility to Europe's armoury for nuclear-physics research.

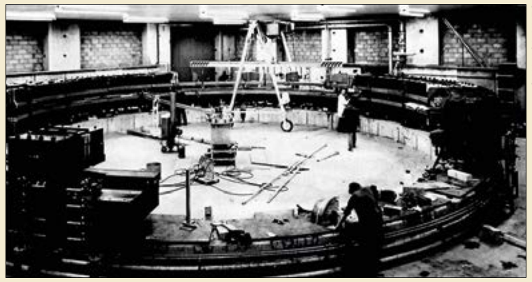
● Compiled from texts on pp85–88.

SIN

The SIN team line up around the ring cyclotron, which they have brought so smoothly into action.

CERN

Muon ring

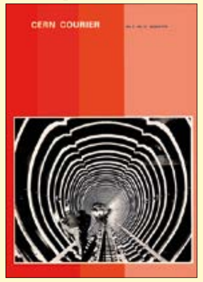


CERN 48.11.73

Under construction, the CERN muon storage ring requires extremely careful assembly since it will be used in an experiment to measure the "g-2" value of the muon anomalous magnetic moment to very high accuracy. The ring will be tested in the summer.

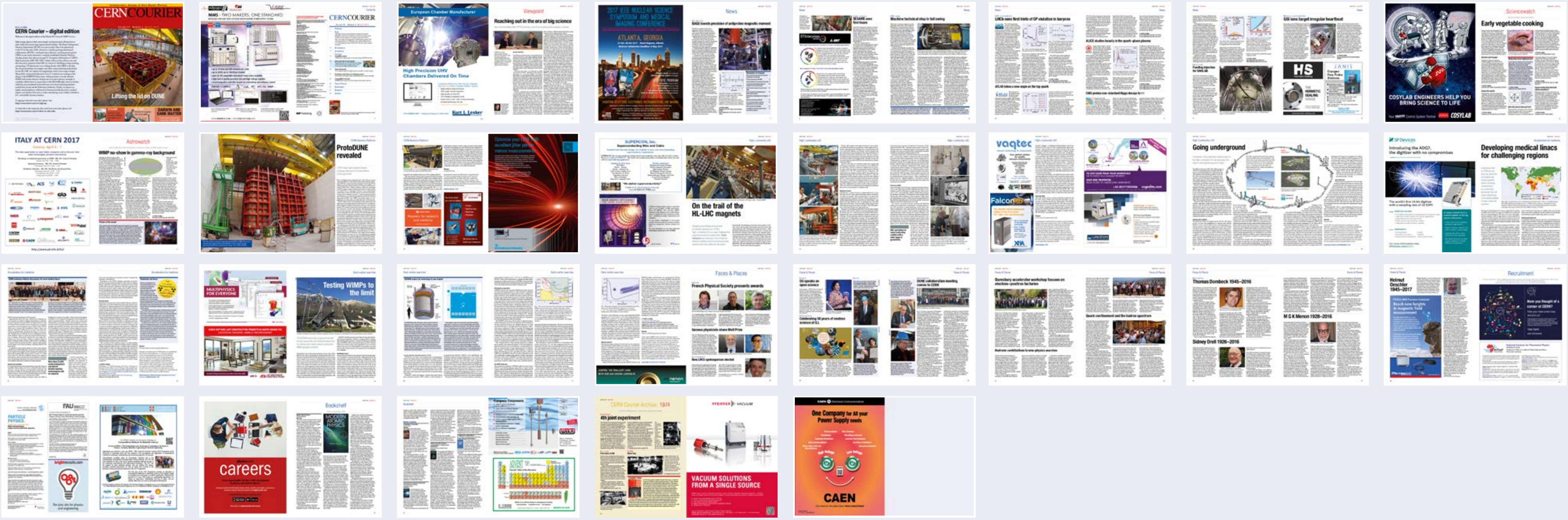
● Compiled from text on p79.

Compiler's Note



By 1979, the anomalous magnetic moment of the muon, g-2, had been measured at CERN to an unprecedented precision of 7.3 ppm, differing significantly from the Standard Model (SM) prediction, a discrepancy that could point to physics beyond the SM. More accuracy was required and investigations continued at BNL Brookhaven, with a 0.54 ppm result reported in 2006. However, the uncertainty was still below the five-standard deviation confidence level needed to test theoretical estimates of the hadronic contribution. So in 2013 the BNL ring was transported intact to Fermilab by land, sea and river – a remarkable feat. There, with much new and improved instrumentation, experiment E989 is aiming to reach 0.14 ppm and first-physics data-taking is expected soon.

The IHEP-CERN teams at the U-70 machine observed the eponymous Serpukhov effect, the rise in total cross-sections for K^+p interactions above about 15 GeV. Subsequent measurements at CERN and Fermilab showed this to be a universal high-energy phenomenon for all hadrons, phenomenologically described by Regge theory as the exchange of "objects" called pomerons. Still fashionable, feasible pomeron structure is being studied by various experiments at the LHC.



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