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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Reaching out in the era of big science

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

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 the opportunity to become particle physicists, all will have the chance to understand and appreciate that the methods currently used to support such dialogue. It has also become evident that the tools and society to maintain an open and transparent dialogue. By Hans Peter Beck

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16/014

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16/014
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 smaller diameters compared to those used for electrons.

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.

Further reading
H Nagashima et al. 2017 Nature Communications 8 15084.
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.

SESA ME, which stands for Synchrotron-light for Experimental Science and Applications in the Middle East, is an international project co-owned by CERN and the Middle East. SESAME saw its first beam of synchrotron light in 2004.

The EYETS is now in full swing, with several interconnections to be opened. On the right is a disconnected magnet that was taken around six months, leading to first optimised for the experiments that will be done. Before the machine enters the SESAME’s main ring, the next step will be to allow important maintenance works to be carried out on the cryogenic system. Since it takes several weeks to refill, pump and “bail out” the cryogenics before the LHC can restart operations, the already busy EYETS schedule is extremely tight. CERN, which is 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.

The EYETS activities themselves. The extended experiments themselves. The extended experiments themselves. The extended

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.

The LHC had been emptied of liquid helium, which normally keeps the superconducting dipole magnets at a temperature of 1.9K, and the bulk of the machine is being held at a temperature of 20K 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 “bail out” the cryogenics before the LHC can restart operations, the already busy EYETS schedule is extremely tight. Cryo-filling of the quench recovery line for the helium tube test was conducted in two of the LHC’s eight sectors before the entire system was gradually increased: in sector 4–5, for example, the current reached 11.35 kA, corresponding to a beam energy of 6.82 TeV. The considerable amount of data collected during the powering tests will be analysed to define the best strategy for reaching the LHC’s full design energy.

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The EYETS activities concern the installation of the cryogenic modules and related infrastructure in 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.

The LHC’s 1252 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 before the entire system was gradually increased: in sector 4–5, for example, the current reached 11.35 kA, corresponding to a beam energy of 6.82 TeV. The considerable amount of data collected during the powering tests will be analysed to define the best strategy for reaching the LHC’s full design energy.

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The detection of beauty baryons provides new insights into CP violation. ATLAS recently reported the first CP-violating measurements of beauty baryons, using data from the LHCb experiment.

**Fig. 1.** Mass spectrum of beauty baryons. The spectra for positive and negative baryons are shown in red and blue, respectively. The peaks correspond to different beauty baryons.

**Fig. 2.** CP-violating asymmetries measured for beauty baryons. The asymmetries are shown as a function of the angle between the decay products. The asymmetry is defined as the ratio of the fraction of events in which the CP-violating decay occurs, to the fraction of events in which it does not.

**Table 1.** Summary of the measured CP-violating asymmetries for beauty baryons.

<table>
<thead>
<tr>
<th>Baryon</th>
<th>Asymmetry (%)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B+</td>
<td>-5.0 ± 1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>B-</td>
<td>-2.0 ± 1.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

These measurements are consistent with the Standard Model predictions and provide new constraints on CP violation.

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**Further reading**:

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**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 timescale in initial hard-scattering processes and thus 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.

In the recent ALICE measurement, the production of beauty baryons is studied in Pb–Pb collisions at the LHC. The results are in agreement with the Standard Model predictions and provide new constraints on CP violation.

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**Further reading**:

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**CMS probes non-standard Higgs decays to ττ**

Recently, the CMS collaboration performed an updated search for neutral Higgs boson decays into ττ pairs, using data recorded during 2016. Although the existence of the Higgs has been established beyond doubt since its debut in the CMS and ATLAS collaborations, 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 8 × 10⁻6 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 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 therefore not easily identified. This peculiar decay pattern is valuable for probing new physics beyond the Standard Model.

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**Further reading**:
neutral pions. The primary difficulty when dealing with the \( \tau \) is the distinction between genuine \( \tau \) leptons and copiously produced quark and gluon jets that can be misidentified as \( \tau \)s.

To identify the dominant \( \tau \) decay modes, CMS has developed a powerful \( \tau \) reconstruction algorithm, which makes use of the single-particlereconstruction procedure (called particle flow). Charged hadrons are combined with photons from neutral pion decays to reconstruct \( \tau \) decays 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 "stripes" 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 \( \tau \) algorithm, along with numerous other analysis techniques, CMS finds no excess of events in which a Higgs decays into two \( \tau \) leptons compared to the expectation from the SM. Instead, upper limits were determined for 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 CMS collaboration.

● Further reading

CMS Collaboration CMS-PAS-TAU-16-002.

The second-generation DEAP-3600 detector at SNOLAB, which uses 3600 kg of liquid argon to search for WIMP's.
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 archaeological 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, leaves, 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.

Further reading

Christoph Opie of University College London in the UK have analysed the bactheums of nearby 4000 mammalian 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 the chimpanzee. This may have coincided with the change towards a more monogamous lifestyle, concludes the team.

Further reading

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.

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 152 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.

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

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.
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Thursday, April 6th, 09:00 - 18:30
Friday, April 7th, 09:00 - 13:00

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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 to what is done for the CMB anisotropies.

The derived auto- and cross-APS are 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 with gamma-ray energies with data from the future Cherenkov Telescope Array and possibly also with high-energy neutrinos detected by IceCube.

Further reading

Fluctuations in the isotropic gamma-ray background (IGRB), based on 31 months of Fermi data. Emissions from our own galaxy and from bright extra-galactic sources are masked in grey.

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Further reading
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...
CERN Neutrino Platform

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 x 1 x 1 m³ 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 kA, 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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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 (Nb₃Sn) material, he says. “Bend it and it breaks like spaghetti.”

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.

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

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 (Nb₃Sn) material, he says. “Bend it and it breaks like spaghetti.”

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“Superconducting niobium-tin cables being wound on the Spirex coil winder at Fermilab. (All image credits: J Ordan/CERN.)
The HL-LHC magnets will be built from Nb3Sn, a new conductor used for the first time in an accelerator. Unlike copper, however, Nb3Sn 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 with 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 dipole that guides 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 Bellentinii, 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 property labels Q1 and Q3, and are a collaboration between three laboratories: Fermilab, BNL and Lawrence Berkeley National Laboratory in California. Nb3Sn technology, whose development has been supported by the US Department of Energy, was not applicable to accelerator magnets until around a decade ago. Now, Nb3Sn 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 Nb3Sn, 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 high defocusing, an Nb3Sn physics divide 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’s Advanced Photon Source (APS), next to a piece of the laboratory’s history: Enrico Fermi’s Argonne facility (above).
High-Luminosity LHC

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 clean surface on the cavity,” he explains. ANL’s chemical processing facility has recently been enlarged to accommodate new buffer chemical polishing and electro-polishing 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, where 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 near-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 les 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 précision. 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.
High-Luminosity LHC

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 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 lhc accelerator technologies, in particular: new 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 accommodate the new components for the HL-LHC, new underground galleries, tunnels and shafts are required at these points.

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 contractors 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 starting construction work by mid-2018. CERN has also performed geotechnical investigations to better understand the underground conditions (which consist of glacial moraines overlaid by 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 m² including 3300 m² of underground civil-engineering work.

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.

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 matériaux 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’aborder les nouveaux infrastructures et les nouveaux éléments, des structures de génie civil, notamment des bâtiments, des piles, des caves, des bâtiments et des systèmes de climatisation, ont été conçus et construits. L’accélérateur, 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.
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 12,000 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 30,000 radiation therapists would be required to deliver this service.

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.

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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 were discussed.

Leading experts were invited from international organisations, government agencies, research institutes, universities and hospitals, and companies that provide equipment for conventional X-ray and particle therapy. Discussions were aimed at helping LMICs establish in-country cancer-care systems based on current hardware technology and software that most of these design considerations relatively quickly requires a repairable and upgraded system. Discussions focused on new solutions and novel technology for a series of radiation-treatment systems that incorporate intelligent software and are modular, rugged and easily operated.

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 is 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 désavantagees
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 désavantagés. 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 Pistenbaum et Norman Coleman, International Cancer Expert Corps, Inc., and Manjit Dosanjh, CERN.
Dark-matter searches

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.

Testing WIMPs to the limit

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.

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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.
Dark-matter searches

Dark-matter searches

or more generally axion-like particles (ALPs).

The technology employed in 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 events.

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 radioluminescence, high quantum efficiency of 35% at 178 nm, a gain of around 5 x 10^9 and a very low dark count rate at ~10^-5. A belt of 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 photomultipliers. A novel concept of liquid-hole multipliers could allow for a faster 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.

The goals of DARWIN are even more ambitious, promising an unprecedented sensitivity of 2.5 x 10^-40 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 super-WIMPs, 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.

The WIMP landscape

The current best sensitivity for 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). This unique arrangement of a low-energy solar neutrinos on electrons is about 6 x 10^-37 cm^2). A further planned upgrade called XENONnT with seven tonnes of 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.

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 XENONnT 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.
Dark-matter searches

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
- DARWIN Collaboration 2016 JCAP:Doi: 10.1088/1475-7516/2016/11/017.

**Résumé**

Pouvoir 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 matière noire. Il utilisera un élément noble, le xénon, sous sa forme liquide, pour détecter des WIMP (soit des particules massives interagissant faiblement), et un atome lourd de 152, 224 et 60 événements, respectivement, avec un seuil de détection de 10⁻⁹ cm².

**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-sections 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 (fig. 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/c² down to the extremely low cross-sections of 1.5×10⁻⁹ cm². Should WIMPs not be observed in the DARWIN detector, the

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**WIMP mass (GeV/c²)**

![Graph showing sensitivity to WIMP mass](image)

**Fig. 2.** Reconstructed parameters for three hypothetical particle masses (20, 100 and 500 GeV/c²) and a cross-section of 2×10⁻¹⁴ cm² using realistic DARWIN detector parameters, backgrounds and astrophysical uncertainties.

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**New LHCb spokesperson elected**

Giovanni Passaleva of the Istituto Nazionale di Fisica Nucleare (INFN) Firenze, Italy, has been appointed as the new 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 CERN 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.

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**Awards**

**French Physical Society presents awards**

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 physique nucléaire de Lyon (IPNL) 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 achievements in physics and has not been awarded for the past few years. The winners of the 2015 Langevin Prize are François Gels 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.

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**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.

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**Exoplanet pioneers Michel Mayor (left) and Didier Queloz.**

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**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.
CERN Courier March 2017

Faces & Places

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.”

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 16 scientific members: Spain, Switzerland, Austria, Italy, the Czech Republic, Sweden, Belgium, Slovakia, DUNIH 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.

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.

Conferences

DUNE collaboration meeting comes to CERN

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 p2). 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 × 1 × 1 m 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 × 6 × 6 m 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

From 24 to 27 October 2016, accelerator experts from around the world gathered in Daresbury, UK, to discuss the status, challenges and vision of circular high-luminosity electron-positron factories. Organised under ICFPA and co-sponsored by the EmCARD-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 HEP 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 Pwinski 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 some 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 timeline 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 NbN 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 and cost-effective two-in-one magnets; ring; magnet tapering; top-up injection; deconfinement; QCD and strongly coupled theories; fields and chiral fermions; light quarks; structure and confinement; emergent gauge theories; and strongly coupled theories. Two additional parallel sessions devoted to statistical methods and instrumentation were also included this year.

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

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; deconfinement; QCD and new physics; nuclear and astroparticle physics; and strongly coupled theories. The conference was followed by a satellite meeting, a new edition of HC2NP covering a selection of timely subtopics which will be organised in Tenerife during 2018.

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 polarisation 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 energy-naming hints of lepton-universality violation in the so-called KK and RPV signals. These signals should be validated at other B-dilepton 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 hyperons are also being investigated. 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 values 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.

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

The first international workshop on Hadronic Contributions to New Physics Searches (HC2NP2016) 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 charge radius.

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OBITUARIES

Faces & Places

Thomas Dombeck 1945–2016

Sidney David Drell, professor emeritus of theoretical physics at SLAC National Accelerator Laboratory, senior fellow at Stanford’s Hoover Institution, and a leading physicist 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.

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 Ramanath Cowsik.

M G K Menon 1928–2016

Mambilakkalathu Govind Kumar Menon, a pioneer in particle physics and a distinguished statesman of science, passed away peacefully on 16 November 2016 at his home in New Delhi, India. He was 88 years old.

Menon won several awards including the Cecil F Powell and C V Raman medals, and was elected to the three scientific academies of India (Indian National Academy of Sciences, the Russian Academy of Sciences, and the Indian Academy of Sciences), the American Academy of Arts and Sciences; the American Philosophical Society, and was president of the American Physical Society in 1986.

Menon was also very close to his wife M G K Menon, a drifter of Indian science.

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 1949. 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 CERN, the ALEPH and ATLAS experiments at the LHC.

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additiona
Helmut Oeschler
1945–2017

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 plasma.

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.

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Hands & Faces

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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.

Applications: Prof Frederik Scholtz on +27 21 808 3871 or at fgs@sun.ac.za.

Requirements: A doctorate of high standing in a field relevant to the research groups and topics at that node.

Duties: Maintaining a vigorous research programme in Condensed Matter/Statistical Physics.

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.

Applications: Must include a letter complete CV, publication list, description of present and future research interests, copies of relevant qualifications, as well as names and addresses/mails of at least 2 referees.

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- Generic development of detectors and accelerators for applications in particle physics

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http://particle-physics.desy.de/education__career/fellowship/index_eng.html

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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Deadline for applications: 31 March 2017
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The Faculty of Sciences invites applications for a

W3 Professorship for Experimental Astroparticle Physics (Tenure Track Heisenberg Professorship) at the Department of Physics, Erlangen Centre for Astroparticle Physics (ECAP), to be filled by the earliest possible starting date.

The successful candidate is expected to represent the field adequately in teaching and research. The position is associated with the research focus Physics and Mathematics of the Centre of the Faculty of Sciences at FAU and will be part of the Erlangen excellence cluster “Junges Universitätskolleg – Exzellenz in der wissen­schaf­lichen Bildung der Menschen.”

The successful candidate is expected to have outstanding international qualifications and shall establish research at ECAP in a field of astroparticle physics that is preferably, not yet represented at FAU. The ECAP laboratory is a research facility which recently received approval, will provide excellent infrastructure for experimental work from 2022 onwards. The successful candidate will collaborate with working groups for astrop­physics, astrophysics, theory, and detector technology. The professorship is to be created as part of the Heisenberg programme of the Deutsche Forschungs­gemeinschaft (DFG). The establishment of the professorship and the appointment are contingent on the candidate’s successful application for a Heisenberg professorship with DFG. According to DFG regulations, the W3 position shall be initially limited to three years. A permanent position may be granted after a positive assessment of the research activities by the DFG and the committee for science policy of the University.

The professorship is to be continued after this three-year period, no new appointment procedure need be carried out.

For further information and the application guideline please see: https://www.fau.de/uni/en/services/all-fau/professuren/

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 (research) funding) to the Dean of the Faculty of Sciences, FAU Erlangen-Nürnberg, Theodor-Heuss-Allee 1, 91058 Erlangen, by 15.4.2017. Please also send an electronic version to nils.dekare@fau.de.

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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 four 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.

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

Probabilistic Methods for Engineers
By Paolo Caio
and Andrea Meucci
Springer

This book aims to provide a concise and practical 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, and simulation.

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 Vashist
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 the quantum properties of light, namely the interference and polarization of photons that are the building blocks for a quantum computer. At the end of each chapter, exercises are provided to help develop the reader’s understanding and skills.

Position-Sensitive Gaseous Photomultipliers: Research and Applications
By Tom Franczak and Vladimir Penkov
IIS 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 position-sensitive detectors. The book provides a detailed comparison between different technologies, highlighting their advantages and disadvantages.

After describing the general 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 photo-sensitive vapours to devices used in liquid and then solid photocathodes. UV-sensitive photodetectors based on cesium fluoride are mainly used as Cherenkov-ring imaging detectors and are currently employed in the ALICE and COMPASS experiments at CERN, as presented in a dedicated chapter.

The latest generation of gaseous photomultipliers enables the visible region, which is 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 Purity (CPLEAR).

The book concludes by presenting the latest generation of RICH detectors and applications of gaseous photomultipliers beyond RICH detectors, completing the overview of the subject.

17 Big Bets for a Better World
By Scott Aaronson
Kargymyan and Koblewski (eds)
Forlaget Historika/Gal Publishers

This book, which includes a contribution by CERN Director-General Fabiola Gianotti, presents 17 radical and game-changing ideas to help reach the 20.30 Global Goals for Sustainable Development identified by the United Nations General Assembly.

Renowned and influential leaders propose innovative solutions for the 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 science and research in education, 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 contemplates why 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.
The 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 \( \pi^- p \rightarrow n + \) neutrals. The Karlsruhe and Pisa groups had examined this interaction at the CERN PS, detecting \( \gamma \)-rays and neutrons in coincidence. They were interested in carrying the study to higher energies, extending the mass range available for \( \pi^- p \) 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 \( \pi^- p \) and \( \pi^- n \) 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.

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.

CERN

Muon ring

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.

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 from the Standard Model (SM) prediction by 0.54 ppm. Since then, the uncertainty has been below the five-standard deviation confidence level needed to test theoretical estimates of the hadronic contribution. So in 2013 the BNL ring was used in an experiment to measure the “g-2” value of the muon anomalous magnetic moment to a high accuracy. The ring will be tested in the summer.

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