WELCOME

CERN Courier – digital edition

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

For more than six decades, CERN has pursued its mission to gain a deeper understanding of the basic constituents of the universe. In doing so, physicists have had to invent technologies to accelerate particles to the highest energies and then detect, store and analyse the outcome of their collisions. Many of these ideas have spread beyond the laboratory's confines, and CERN's knowledge-transfer activities in recent years have led to hundreds of collaboration agreements with firms and organisations and tens of new companies established across sectors ranging from health to space. Innovative technologies are at the heart of the LHC Injectors Upgrade project, which is currently in full swing to prepare CERN's accelerator complex for the demands of the high-luminosity LHC. We also report on a recent workshop in Nepal highlighting the opportunities for high-energy physics and CERN in the South Asia region, and summarise the latest efforts to better model neutrino-nuclei interactions for future long-baseline neutrino experiments such as DUNE in the US.

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EDITOR: MATTHEW CHALMERS, CERN
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Covering current developments in high-energy physics and related fields worldwide

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Editor Matthew Chalmers
Books editor Virginia Greco
CERN, 1211 Geneva 23, Switzerland
E-mail cern.courier@cern.ch
Fax +41 (0) 22 76 69070
Web cerncourier.com

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IOP Publishing Ltd, Temple Circus, Temple Way,
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Publisher Susan Curtis
Production editor Lisa Gibson
Technical illustrator Alison Tovey
Group advertising manager Chris Thomas
Advertisement production Katie Graham
Marketing & Circulation Angela Gage

Head of B2B & Marketing Jo Allen
Art director Andrew Giaquinto

Advertising
Tel +44 (0)117 930 1026 (for UK/Europe display advertising)
or +44 (0)117 930 1164 (for recruitment advertising);
E-mail: sales@cerncourier.com; fax +44 (0)117 930 1178

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China Ya'ou Jiang, Institute of High Energy Physics,
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E-mail: jiangyo@mail.ihep.ac.cn
Germany Antje Brandes, DESY, Notkestr. 85, 22607 Hamburg, Germany
E-mail: desypr@desy.de
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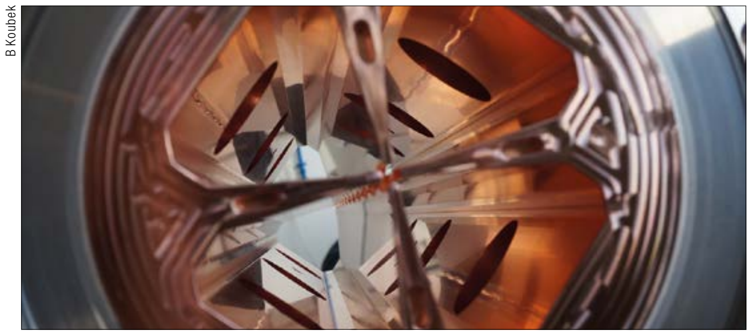
On the cover: The Timepix3 chip, a multipurpose hybrid pixel detector developed within the Medipix3 collaboration. (Image credit: M Brice/CERN.)

Viewpoint

CERN's recipe for knowledge transfer

Since 1997, CERN has enhanced its efforts to put its technology and know-how to the greater good.

B Koubek



CERN has developed a radio-frequency quadrupole for a miniature linear accelerator ideal for medical and industrial applications, with the technology licensed to a spin-off company.

By Giovanni Anelli

Understanding what the universe is made of and how it started are the fundamental questions behind CERN's existence. This quest alone makes CERN a unique knowledge-focused organisation and an incredible human feat. To achieve its core mission, CERN naturally creates new opportunities for innovation. A myriad of engineers, technicians and scientists develop novel technology and know-how that can be transferred to industry for the benefit of society. Twenty years ago, with the support of CERN Council, a reinforced structure for knowledge and technology transfer was established to strengthen these activities.

Advances in fields including accelerators, detectors and computing have had a positive impact outside of CERN. Although fundamental physics might not seem the most obvious discipline in which to find technologies with marketable applications, the many examples of applications of CERN's technology and know-how – whether in medical technology, aerospace, safety, the environment and "industry 4.0" – constitute concrete evidence that high-energy physics is a fertile ground for innovation. That CERN's expertise finds applications in multinational companies, small and medium enterprises and start-ups alike is further proof of CERN's broader impact (see p17).

As an international organisation, CERN has access to a wealth of diverse viewpoints, skills and expertise. But what makes CERN different from other organisations in other fields of research? Sociologists have long studied the structure of scientific organisations, several using CERN as a basis, and they find that particle-physics collaborations uniquely engage in "participatory collaboration" that brings added value in knowledge generation, technology development and innovation. This type of collaboration, along with the global nature of the experiments hosted by CERN, adds high value to the laboratory's knowledge-transfer activities.

Despite its achievements in knowledge transfer internationally, CERN is seldom listed in international innovation rankings; when it is present, it is never at the top. This is mainly a selection effect due to methodology. For example, the Reuters "Top 25 Global Innovators – Government" ranking relies on patents as a proxy for innovation (of the 10 innovation criteria used, seven are based on patents). CERN's strategy is to focus on open innovation and to maximise the dissemination of our technologies and know-how, rather than focus on revenue. Although there is a wide range of intellectual-property tools useful for knowledge transfer, patent volume is not a relevant measure of successful intellectual-property management at CERN.

Instead, the CERN Knowledge Transfer group measures the number of new technology disclosures (91 in 2016), and the number of contracts and agreements signed with external partners and industry (42 in 2016, and totalling 251 since 2011). We also monitor spin-off and start-up companies – there are currently 18 using CERN technology, some of which are hosted directly in CERN's network of business incubation centres. Together with the impressive breadth of application fields of CERN technologies, we believe these are clearer measures of impact.

In the future, CERN will continue to pursue and promote open innovation. We want to build a culture of entrepreneurship whereby more people leaving CERN consider starting a business based on CERN technologies, and use a wide range of metrics to quantify our innovation. Strong links with industry are important to help reinforce a market-pull rather than technology-push approach. The Knowledge Transfer group will also continue to provide a service to the CERN community through advice, support, training, networks and infrastructure for those who wish to engage with industry through our activities.

Human capital is vital in our equation, since knowledge transfer cannot happen without CERN's engineers, technicians and physicists. Our role is to facilitate their participation, which could start with a visit to our new website, an Entrepreneurship Meet-Up (EM-U), or a visit to one of our seminars. Since they were launched roughly two years ago, EM-Us and knowledge-transfer seminars have together attracted more than 2000 people. Whether you want to tell us about an idea you have, or are curious about the impact of our technologies on society, we hope to hear from you soon.

● Find out more at kt.cern.

Giovanni Anelli is head of the CERN Knowledge Transfer group.

News

NEUTRINO PLATFORM

Construction of protoDUNE detector begins

The Deep Underground Neutrino Experiment (DUNE) in the US, the cavern for which entered construction this summer, will make precision studies of neutrinos produced 1300 km away at Fermilab as part of the international Long-Baseline Neutrino Facility. The DUNE far detector will be the largest liquid-argon (LAr) neutrino detector ever built, comprising four cryostats holding 68,000 tonnes of liquid, and prototype detectors called protoDUNE are being built at CERN.

Each protoDUNE detector comprises a 10 × 10 × 10 m LAr time projection chamber with a single-phase (SP) or dual-phase (DP) configuration, containing about 800 tonnes of LAr. While the two big cryostats housing the detectors are about to be completed, the construction of the protoDUNE detectors themselves has just started. The first of six anode-plane-assembly modules for the protoDUNE-SP detector, which will detect electrons produced by ionising particles passing through the detector (pictured) recently arrived at CERN. The module will be tested, together with its electronics, and then installed in its final position inside the cryostat.

J Ordan/CERN

The first anode-plane-assembly module for the single-phase protoDUNE, measuring 6 m high and 2.5 m wide.

In parallel with the anode-plane-assembly, other parts of the protoDUNE-SP detector are being assembled at CERN, including the field cage, which keeps the electric field uniform inside the volume of the detector. Around a quarter of the 28 field-cage modules have already been assembled and are stored in CERN's EHN1 hall, ready to be installed. The assembly and installation of the detector parts is expected to be completed by spring next year, in order for protoDUNE-SP to take data in autumn 2018.

The protoDUNE detectors are among several major activities taking place at the CERN neutrino platform, which was initiated in 2013 to develop detector technology for neutrino experiments in the US and Japan.

DARK MATTER

Study links solar activity to exotic dark matter

The origin of solar flares, powerful bursts of radiation appearing as sudden flashes of light, has puzzled astrophysicists for more than a century. The temperature of the Sun's corona, measuring several hundred times hotter than its surface, is also a long-standing enigma.

A new study suggests that the solution to these solar mysteries is linked to a local action of dark matter (DM). If true, it would challenge the traditional picture of DM as being made of weakly interacting massive particles (WIMPs) or axions, and suggest that DM is not uniformly distributed in space, as is traditionally thought.

The study is not based on new experimental data. Rather, lead author Sergio Bertolucci, a former CERN research director, and collaborators base their conclusions on freely available data recorded over a period of decades by geosynchronous satellites. The paper presents a statistical analysis of the occurrences of around 6500 solar flares in the period 1976–2015 and of the continuous solar emission in the extreme ultraviolet (EUV) in the period 1999–2015. The temporal distribution of these phenomena, finds the team, is correlated with the positions of the Earth and two of its neighbouring planets: Mercury and Venus. Statistically significant (above 5σ) excesses of the number of flares with respect to randomly distributed occurrences are observed when one or more of the three planets find themselves in a slice of the ecliptic plane with heliocentric longitudes of 230°–300°. Similar excesses are observed in the same range of longitudes when the solar irradiance in the EUV region is plotted as a function of the positions of the planets.

These results suggest that active-Sun phenomena are not randomly distributed, but instead are modulated by the positions of the Earth, Venus and Mercury. One possible explanation, says the team, is the existence of a stream of massive DM particles with a preferred direction, coplanar to the ecliptic plane, that is gravitationally focused by the planets towards the Sun when one or more ▷

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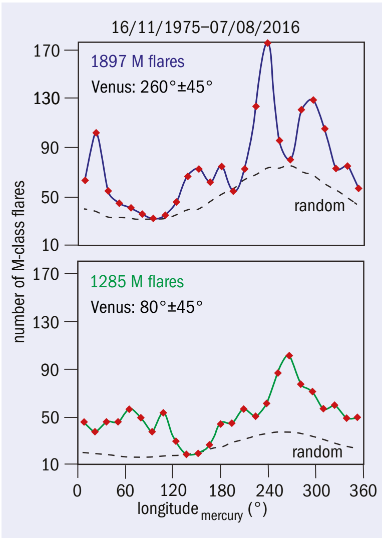
of the planets enter the stream. Such particles would need to have a wide velocity spectrum centred around 300 km s^{-1} and interact with ordinary matter much more strongly than typical DM candidates such as WIMPs. The non-relativistic velocities of such DM candidates make planetary gravitational lensing more efficient and can enhance the flux of the particles by up to a factor of 10^6, according to the team.

Co-author Konstantin Zioutas, spokesperson for the CAST experiment at CERN, accepts that this interpretation of the solar and planetary data is speculative – particularly regarding the mechanism by which a temporarily increased influx of DM actually triggers solar activity. However, he says, the long persisting failure to detect the ubiquitous DM might be due to the widely assumed small cross-section of its constituents with ordinary matter, or to erroneous DM modelling. "Hence, the so-far-adopted direct-detection concepts can lead us towards a dead end, and we might find that we have overlooked a continuous communication between the dark and the visible sector."

Models of massive DM streaming particles that interact strongly with normal matter are few and far between, although the authors suggest that "antiquark nuggets" are best suited to explain their results. "In a few words, there is a large 'hidden' energy in the form of the nuggets," says Ariel Zhitnitsky, who first proposed the quark-nugget dark-matter model in 2003. "In my model, this energy can be precisely released in the form of the EUV radiation when the anti-nuggets enter the solar corona and get easily annihilated by the light elements present in such a highly ionised environment."



Distributions of M-class solar flares as a function of Mercury's heliocentric longitude with the constraint of Venus being at longitude between 215°–305° (top) and between 35°–125° (bottom). The dotted black lines represent the expected number of flares if they were equally distributed in time.

The study calls for further investigation, says researchers. "It seems that the statistical analysis of the paper is accurate and the obtained results are rather intriguing," says Rita Bernabei, spokesperson of the DAMA experiment, which for the first time in 1998 claimed to have detected dark matter in the form of WIMPs on the basis of an observed seasonal modulation of a signal in their scintillation detector. "However, the paper appears to be mostly hypothetical in terms of this new type of dark matter."

The team now plans to produce a full simulation of planetary lensing taking into account the simultaneous effect of all the planets in the solar system, and to extend the analysis to include sunspots, nano-flares and other solar observables. CAST, the axion solar telescope at CERN, will also dedicate a special data-taking period to the search for streaming DM axions.

"If true, our findings will provide a totally different view about dark matter, with far-reaching implications in particle and astroparticle physics," says Zioutas. "Perhaps the demystification of the Sun could lead to a dark-matter solution also."

● Further reading

S Bertolucci *et al.* 2017 *Phys. Dark Universe* **17** 13.

Detectors

Miniature detector first to spot coherent neutrino-nucleus scattering

The COHERENT collaboration at Oak Ridge National Laboratory (ORNL) in the US has detected coherent elastic scattering of neutrinos off nuclei for the first time. The ability to harness this process, predicted 43 years ago, offers new ways to study neutrino properties and could drastically reduce the scale of neutrino detectors.

Neutrinos famously interact very weakly, requiring very large volumes of active material to detect their presence. Typically, neutrinos interact with individual protons or neutrons inside a nucleus, but coherent elastic neutrino-nucleus scattering (CEvNS) occurs when a neutrino interacts with an entire nucleus. For this to occur, the momentum exchanged must remain significantly small compared to the nuclear size. This restricts the process to neutrino energies below a few tens of MeV, in contrast to the charged-current interactions by which neutrinos are usually detected. The signature of CEvNS is a low-energy nuclear recoil with all nucleon wavefunctions remaining in phase, but until now the difficulty in detecting these low-energy nuclear recoils has prevented observations of CEvNS – despite the predicted cross-section for this process being the largest of all low-energy neutrino couplings.

The COHERENT team, comprising 80 researchers from 19 institutions, used ORNL's Spallation Neutron Source (SNS), which generates the most intense pulsed neutron beams in the world while simultaneously creating a significant yield of low-energy neutrinos. Approximately 5×10^{20} protons are delivered per day, each returning roughly 0.08 isotropically emitted neutrinos per flavour. The researchers placed a detector, a caesium-iodide scintillator crystal doped with sodium, 20 m from the neutrino source with shielding to reduce background events associated with the neutron-induced nuclear recoils produced from the SNS. The results favour the presence of CEvNS over its absence at the 6.7σ level, with 134±22 events observed versus 173±48 predicted.

Placing the caesium-iodide detector, possibly the first handheld neutrino detector, in the path of the SNS beam.

Crucially, the result was achieved using the world's smallest neutrino detector, with a mass of 14.5 kg. This is a consequence of the large nuclear mass of caesium and iodine, which results in a large CEvNS cross-section. The intense scintillation of this material for low-energy nuclear recoils, combined with the large neutrino flux of the SNS, also contributed to the success of the measurement. In effect, CEvNS allows the same detection rates as conventional neutrino detectors that are 100 times more massive.

"It is a nearly ideal detector choice for coherent neutrino scattering," says lead designer Juan Collar of the University of Chicago. "However, other new coherent neutrino-detector designs are appearing over the horizon that look extraordinarily promising in order to further reduce detector mass, truly realising technological applications such as reactor monitoring."

Yoshi Uchida of Imperial College London, who was not involved in the study, says that detecting neutrinos via the neutral-current process as opposed to the usual charged-current process is a great advantage because it is "blind" to the type of neutrino being produced and is sensitive at low energies. "So in combination with other types of detection, it could tell us a lot about a particular neutrino source of interest." However, he adds that the SNS set-up is very specific and that, outside such ideal conditions, it might be difficult to scale a similar detector in a way that would be of practical use. "The fact that the COHERENT collaboration already has several other target nuclei (and detection methods) being used in their set-up means there will be more to come on this subject in the near future."

● Further reading

COHERENT Collaboration 2017 *Science*
DOI: 10.1126/science.aao0990.

Outreach

Particle Zoo searching for new keeper

The Particle Zoo, a California-based company that produces soft-toy versions of elementary particles and other outreach materials, is searching for a buyer to take the reins.

Julie Peasley, a graphic designer with a keen interest in physics, started the company in 2008 after having attended a public lecture about cosmology at the University of California at Los Angeles and a craft fair in the same weekend. Setting up an online store, she began selling her particles, slowly expanding the range after requests from physicists. Beginning with little sewing experience, Peasley can now produce around four particle toys per hour and has created more than 50,000 units to date.

Each of the Zoo's 36 felt particles, plus a range of related products from stickers to pillows, is designed to reflect the properties of its real counterpart: the W boson is double-sided to represent its positive and negative aspects; neutrinos are masked to reflect their elusive nature; and each toy is stuffed with a different material to reflect the mass hierarchy of the real particles.

Looking for a new career path, Peasley says the business has tremendous potential for growth with the right owner and a little capital. "To this day, there are no competitors – I am still the only person selling plush particles! I just never had the capital to take it to the next level," she told *CERN Courier*.

Peasley piloted the mass-production of her two most popular particles – the Higgs boson and the electron – in China for three years. However, she struggled to secure the investment required to continue with the mass-production of all the particles. "I'd really love to see the business continue rather than die because it brings smiles to anyone who sees it." Interested potential particle zookeepers can get in touch at particlezoo.net.

Julie Peasley's hand-sewn felt particles have been into space with astronaut Christer Fuglesang and Peter Higgs uses his own Particle Zoo boson as a paperweight.

Machine learning improves cosmic citizen science

Launched in 2014, the Distributed Electronic Cosmic-ray Observatory (DECO) enables Android smartphone cameras to detect cosmic rays. In response to the increasing number of events being recorded, however, the DECO team has developed a new machine-learning analysis that classifies 96% of events correctly.

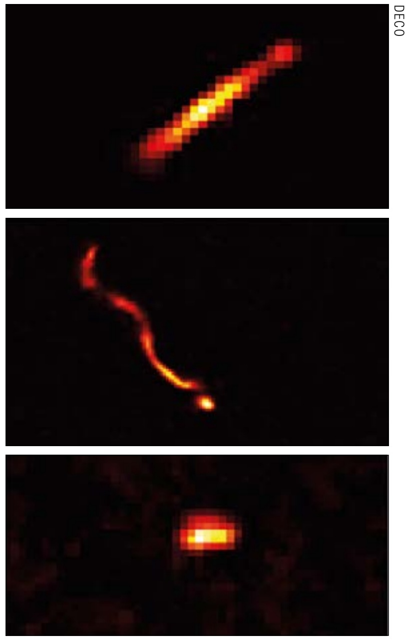
Similar to detectors used in high-energy physics experiments, the semiconductors in smartphone camera sensors detect ionising radiation when charged particles traverse the depleted region of their sensor. The DECO app can spot three distinct types of charged-particle events: tracks, worms and spots (see image). Each event can be caused by a variety of particle interactions, from cosmic rays to alpha particles, and a handful of events can be expected every 24 hours or so.

These events have so far been classified by the users themselves, but the increasing number of images being collected meant there was a need for a more reliable computerised classification system. Due to the technological variations of smartphones and the orientation of the sensor when a cosmic ray strikes, traditional algorithms would have struggled to classify events.

The DECO team used advances in machine learning similar to those widely used in high-energy physics to design several deep neural-network architectures to classify the images. The best performing design, which contained over 14 million learnable parameters and was trained with 3.6 million images, correctly sorted 96% of 100 independent images. An iOS version of DECO is currently in the beta stage and is expected to be released within the next year.

● Further reading

M Meehan *et al.* 2017 arXiv:1708.01281.



(From top) Tracks indicate a muon produced by a cosmic ray, worms indicate an electron produced by a radioactive decay, and spots indicate an electron or gamma ray.

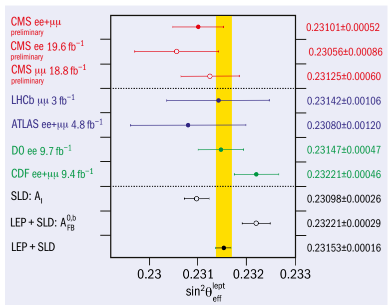
LHC EXPERIMENTS

Precise measurement of $\sin^2\theta_W$ at CMS

In addition to the direct production of new particles in high-energy collisions, evidence for new physics beyond the Standard Model (SM) could arise through precision measurements. Two particularly important parameters in this regard are the mass of the W boson, M_w, and the electroweak mixing angle, $\sin^2\theta_W$. The CMS collaboration has recently reported a precise measurement of the effective electroweak mixing angle based on Drell–Yan production of leptons.

The electroweak mixing angle is a key parameter defining how the SM unifies the electromagnetic and weak forces, and at first order it is related to the W and Z bosons masses by the simple expression: $\sin^2\theta_W = 1 - M_W^2/M_Z^2$. An uncertainty in $\sin^2\theta_W$ of ±0.0005 is equivalent to an indirect measurement of M_w to a precision of 25 MeV, which corresponds to the precision of the direct measurements at hadron colliders.

The most precise measurements of $\sin^2\theta_W$ were performed at the LEP and SLD electron–positron collider at CERN and SLAC. While the uncertainties are small (0.00026 and 0.00029), the central values differ by more than three standard deviations, motivating further precise measurements. CMS aims to measure $\sin^2\theta_W$ with a precision matching LEP and SLD based on the forward–backward asymmetry of lepton pairs with an invariant mass near M_Z. The asymmetry of the production of a negative lepton with respect to the direction of the quark is small in this region, as a result of the axial-vector Z boson self-interference, and is sensitive to the effective mixing angle, $\sin^2\theta_{\rm eff}^{\rm lept}$. In contrast, the asymmetry at higher and lower mass is much larger, originating from the interference of the weak and electromagnetic interactions, and this asymmetry is not sensitive to $\sin^2\theta_{\rm eff}^{\rm lept}$. The leptons are produced via quark–antiquark annihilation in the LHC's proton–proton collisions, and limited knowledge about the quark and antiquark parton distribution functions (PDFs) lead to systematic uncertainties that currently dominate the measurement uncertainty.



Measured values of $\sin^2\theta_{eff}^{lept}$ in the muon and electron channels and their combination compared to previous measurements, with the shaded band showing the combined LEP and SLC measurements.

Using a novel technique with lepton pairs at high and low invariant mass to reduce the PDF uncertainties, CMS has analysed the full electron and muon data samples recorded at an energy of 8 TeV and finds that the effective mixing angle, 0.23101±0.00052, is consistent with the SM prediction 0.23152±00005. With analysis of the 13 TeV LHC data, we can expect that the uncertainties will be significantly smaller and test the electroweak sector further.

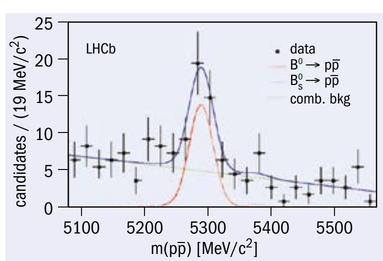
Further reading

CMS Collaboration 2017 CMS-PAS-SMP-16-007.

The rarest B^0 decay ever observed

The LHCb collaboration has observed the rare baryonic decay $B^0 \to p\bar{p}$, as first presented at the European Physical Society conference in Venice in early July. The branching fraction was measured at the level of about 1.3 per 100 million decays, which makes this decay mode the rarest decay of a B^0 meson ever observed. It is also the rarest observed hadronic decay of all beauty mesons.

Our knowledge of baryonic B decays has increased considerably in the last few years. The LHCb experiment, which is primarily designed to search for new physics in CP-violation and rare decays of particles with heavy flavour, has been pursuing a programme to study the decays of B mesons to final states containing baryons. Among the recent achievements it is worth emphasising the first observation of a baryonic B_c^0 decay, $B_s^0 \to p\bar{\Lambda}K^-$, and that of B^0 and B_s^0 decays to $p\bar{p}$ plus a pair of light charged mesons. The B_s^0 is the last of the B meson species for which a baryonic decay mode had yet to be observed. The large data samples available at LHCb have made it possible to study the two-body baryonic final-state decays, which are suppressed with respect to higher-multiplicity decay modes.



Invariant mass distribution of $p\bar{p}$ candidates after full selection, showing the striking peak due to $B^0 \to p\bar{p}$ decays. The fit result (blue line) is shown together with each fit model component.

A search for the rare decays $B^0 \to p\bar{p}$ and $B_s^0 \to p\bar{p}$ had previously been performed by LHCb with 2011 data only, obtaining evidence for $B^0 \to p\bar{p}$. The collaboration now used the full 3 fb^{-1} data sample collected during the first run of the LHC, approximately three times more data than in the previous search, to confirm the evidence for this decay. An excess of $B^0 \to p\bar{p}$ candidates with respect to the background-only hypothesis is now observed with a statistical significance of 5.3 standard deviations. The hint of a $B_s^0 \to p\bar{p}$ signal reported in 2013 is, however, not confirmed, and an upper limit for the corresponding branching fraction has been set.

The measured $B^0 \to p\bar{p}$ and $B_s^0 \to p\bar{p}$ branching fractions are compatible with the latest theoretical calculations. The observation of the latter will allow a quantitative comparison of various QCD-inspired models describing baryonic B decays.

Further reading

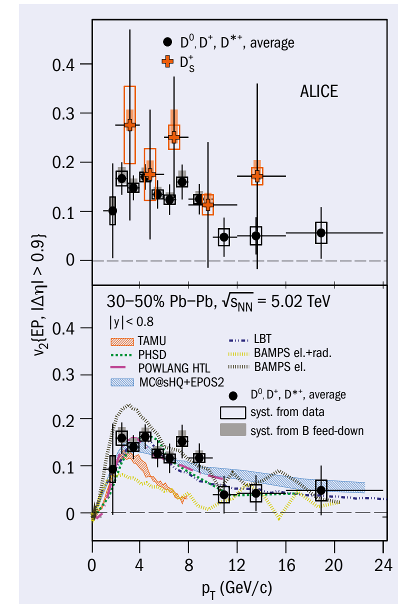
LHCb Collaboration 2017 LHCb-PAPER-2017-022.
LHCb Collaboration 2017 *Phys. Rev. Lett.* **119** 041802.
LHCb Collaboration 2017 LHCb-PAPER-2017-005.

Charm flow in the quark–gluon plasma

The ALICE collaboration has reported a measurement of the azimuthal anisotropy in the production of D mesons, which contain a charm quark, when measured relative to the estimated reaction plane of lead–lead collisions at 5.02 TeV at LHC Run 2. The new measurement is a factor two more precise than the Run 1 measurement and clearly indicates that charm takes part in the collective flow of the colour-deconfined quark–gluon plasma (QGP).

Since heavy quarks are produced in hard-scattering processes on a timescale shorter than the QGP formation time, they experience all stages of the system's evolution. Evidence of interactions between charm quarks and the medium is provided by the observed strong modification of the transverse momentum (p_T) distribution of D mesons in heavy-ion collisions with respect to pp collisions. This is understood in terms of elastic scatterings and gluon-radiation in the medium. Measurements of anisotropies in the azimuthal distribution of heavy-flavour hadrons provide further information to determine the transport properties of the medium. The QGP expansion converts the initial spatial anisotropy, which originates from the geometry of the collision, into a particle-momentum anisotropy. The elliptic anisotropy is characterised by the second Fourier coefficient (v_2) of the particle's azimuthal angle distribution relative to the estimated reaction plane.

The measurement of v_2 for the D meson addresses the issue of whether the flow that is generated by the expansion of the collision system and is known to affect light quarks is also imparted to the much heavier charm quarks. Additionally, hadronisation of charm quarks via recombination with light quarks could contribute to the D-meson flow. This motivates a comparison of the v_2 of D mesons with and without strange-quark content.



(Top) Average non-strange D-meson v_2 as a function of p_T compared to the D_s^+ v_2. (Bottom) Comparison of the average non-strange D-meson v_2 to theoretical calculations including charm-quark interactions with the constituents of an expanding QGP.

ALICE measured the v_2 of D^0, D^+, D^{*+} and, for the first time at the LHC, of D_s^+ mesons in mid-central lead–lead collisions at an energy of 5.02 TeV per nucleon. The average v_2 of non-strange D mesons is larger than zero and similar to that of pions, which is compatible with a similar recent measurement by CMS. The D_s^+ v_2 was found to be positive and compatible with that of non-strange D mesons (top panel of the figure). The improved precision of the new measurement compared to the Run 1 measurement at an energy of 2.76 TeV per nucleon will significantly improve the determination of the heavy-quark diffusion coefficient in the QGP at LHC, which is one of the fundamental properties of this exotic form of matter.

Further reading

ALICE Collaboration 2017 arXiv:1707.01005.

ATLAS hunts for new physics with dibosons

Beyond the Standard Model of particle physics (SM), crucial open questions remain such as the nature of dark matter, the overabundance of matter compared to antimatter in the universe, and also the mass scale of the scalar sector (what makes the Higgs boson so light?). Theorists have extended the SM with new symmetries or forces that address these questions, and many such extensions predict new resonances that can decay into a pair of bosons (diboson), for example: VV, Vh, Vγ and γγ, where V stands for a weak boson (W and Z), h for the Higgs boson, and γ is a photon.

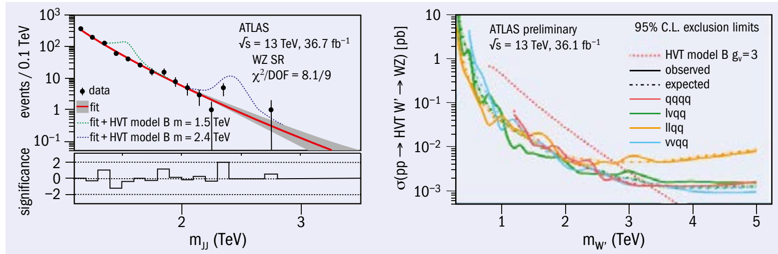
The ATLAS collaboration has a broad search programme for diboson resonances, and the most recent results using 36 fb^{-1} of proton–proton collision data at the LHC taken at a centre-of-mass energy of 13 TeV in 2015 and 2016 have now been released. Six different final states characterised by different boson decay modes were considered in searches for a VV resonance: 4ℓ, $\ell\ell\nu\nu$, $\ell\ell qq$, $\ell\nu qq$, $\nu\nu qq$ and qqqq, where ℓ, ν and q stand for charged leptons (electrons and muons), neutrinos and quarks, respectively. For the Vh resonance search, the dominant Higgs boson decay into a pair of b-quarks (branching fraction of 58%) was exploited together with four different V decays leading to $\ell\ell bb$, $\ell\nu bb$, $\nu\nu bb$ and qqbb final states. A Zγ resonance was sought in final states with two leptons and a photon.

A new resonance would appear as an excess (bump) over the smoothly distributed SM background in the invariant mass distribution reconstructed from the final-state particles. ▷

News

The left figure shows the observed WZ mass distribution in the qqqq channel together with simulations of some example signals. An important key to probe very high-mass signals is to identify high-momentum hadronically decaying V and h bosons. ATLAS developed a new technique to reconstruct the invariant mass of such bosons combining information from the calorimeters and the central tracking detectors. The resulting improved mass resolution for reconstructed V and h bosons increased the sensitivity to very heavy signals.

No evidence for a new resonance was observed in these searches, allowing ATLAS to set stringent exclusion limits. For example, a graviton signal predicted in a model with extra spatial dimensions was excluded up to masses of 4 TeV, while heavy weak-boson-like resonances (as predicted in composite Higgs boson models) decaying to WZ bosons are excluded for masses up to 3.3 TeV. Heavier Higgs partners can be excluded up to masses of about 350 GeV, assuming specific model parameters.



WZ invariant mass spectrum in the qqqq channel (left) and upper limits on the cross-section times branching ratio of a hypothetical boson decaying into a WZ pair (right). The signals are taken from a composite Higgs boson model.

● **Further reading**

ATLAS Collaboration 2017 ATLAS-CONF-2017-051.
ATLAS Collaboration 2017 arXiv:1708.04445.
ATLAS Collaboration 2017 ATLAS-CONF-2017-055.
ATLAS Collaboration 2017 arXiv:1707.06958.
ATLAS Collaboration 2017 ATLAS-CONF-2017-058.
ATLAS Collaboration 2017 arXiv:1708.00212.
ATLAS Collaboration 2017 arXiv:1707.04147.

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

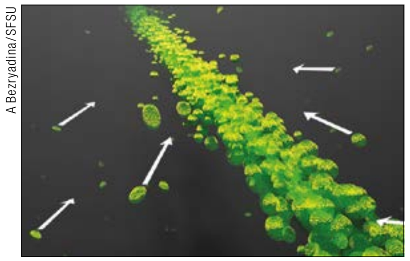
CERN Courier welcomes contributions from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

Sciencewatch

Compiled by John Swain, Northeastern University

Bacteria light the way

Biological media are not usually thought capable of guiding light because they do not exhibit large nonlinear optical responses, but a new study by Zhigang Chen of San Francisco State University and colleagues changes this picture. The team sent a 50 μm-wide green laser beam into a 4 cm-long tube of seawater, upon which the beam broadened to 650 μm, largely due to normal diffraction. Then a strain of cyanobacteria called *Synechococcus*, which do not move on their own and thus could not actively enter or leave the beam, were added to the tube. At low power (0.1 W) the beam diffraction doubled, but at 3 W the beam constricted to a 0.2 mm needle – with almost all bacteria left unharmed. The data could only be explained by taking into account radiation pressure, which is more important in cells with internal structures. Similar results with *E. coli* and human red blood cells suggests analogous self-focusing could provide ways to send light through normally opaque tissues for treatment or imaging.



A Bezryadina/SFSU

Bacteria are drawn inward and forward by a light beam, creating a waveguide that helps reduce the spread of the beam.

● **Further reading**

A Bezryadina *et al.* 2017 *Phys. Rev. Lett.* **119** 058101.

Solar neutrinos probe Earth

Oscillations of solar neutrinos could provide valuable information on the internal structure of the Earth, according to a new study. Ara Ioannisian of the Yerevan Physics Institute in Armenia and colleagues argue that the relative number of ν_e events detected during the day compared to those collected at night could be affected by the layer-like structure of Earth's density, allowing a tomographic scan of the Earth's interior. Specifically, the team studied the possibilities with the future long-baseline DUNE experiment in the US, which expects to see around 75 neutrino events per day in a 40 kt-active mass detector. Five years of data should, in addition to establishing the day–night asymmetry to a level of six standard deviations and providing valuable information on the squared mass difference between the lightest neutrinos, provide confirmation of the layer model of the Earth.

● **Further reading**

A Ioannisian *et al.* 2017 *Phys. Rev. D* **96** 036005.

Nutmeg cooler than menthol

Menthol is a ubiquitous cooling agent used in a wide variety of products. But it turns out that nutmeg packs a punch 30 times stronger, making it the most powerful natural cooling agent known. Tomohiro Shirai and colleagues at Kao Corporation in Tochigi, Japan, identified a neolignan compound (a class of compounds that bind to a cold-sensitive ion channel in the body to trigger a cooling sensation) in nutmeg that binds at a different molecular site than menthol, suggesting that the two might be usefully combined. Used in mouthwash for a 30 second rinse, the new compound took five minutes to kick in as strongly as menthol, but then gave a cooling sensation lasting 30 minutes instead of menthol's 10 minutes.

● **Further reading**

T Shirai 2017 *ACS Med. Chem. Lett.* **8** 715.

Squid vision

Spherical lenses suffer from optical aberration, which prevents all rays from being focused to a single point. As long ago as 1854, James Clerk Maxwell proposed a mathematical solution to this problem by making the refractive index decrease parabolically from the centre to the edge. Although hard to implement in practice, Alison Sweeney and colleagues at the University of Pennsylvania in the US have now shown that squid already perform this trick via assemblies of transparent S-crystallin protein dimers that vary in size to achieve what Maxwell suggested. The stability of the gradient index of refraction is remarkable, suggesting an anisotropic interaction between the proteins to maintain it, and the finding suggests new ways to make aberration-free lenses.

● **Further reading**

J Cai *et al.* 2017 *Science* **357** 564.

A squid showing spherical gradient-index lenses that can correct optical aberration.

Lithium battery reversed

In a conventional lithium-ion battery, ions moving inside the medium power electrons through an external circuit. In an ingenious reversal of this idea, an "electron battery" sees electrons moving internally while ions are pushed through an external circuit. Liangbing Hu of the University of Maryland in College Park and colleagues have made a prototype with a lithium-anode and vanadium-oxide cathode immersed in an organic electrolyte that stimulates the flow of calcium ions inside living cells derived from human embryonic kidney cells. Biocompatibility was achieved by using Kentucky bluegrass stems soaked in salt solution as ionic cables to connect to the cells. The drifting sodium ions then generate an electric field that releases calcium ions, demonstrating a novel electro-biomedical technology with potential applications including nerve and muscle stimulation.

● **Further reading**

C Wang *et al.* 2017 *Nat. Commun.* **8** 15609.

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Astrowatch

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

Optical survey pinpoints dark-matter structure

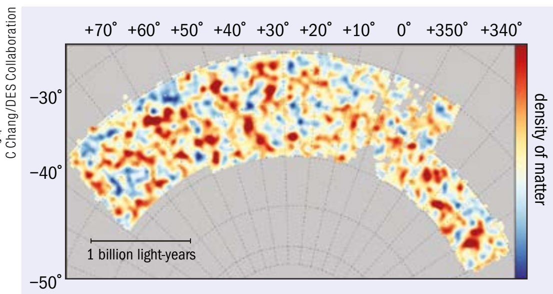
During the last two decades the WMAP and Planck satellites have produced detailed maps of the density distribution of the universe when it was only 380,000 years old – the moment electrons and protons recombined into neutral hydrogen, producing today's cosmic microwave background (CMB). The CMB measurements show that the distribution of both normal and dark matter in the universe is inhomogeneous, which is explained via a combination of inflation, dark matter and dark energy: initial quantum fluctuations in the very early universe expanded and continued to grow as gravity pulled matter together while dark energy worked to force it apart. Data from the CMB have allowed cosmologists to predict a range of cosmological parameters such as the fractions of dark energy, dark matter and normal matter.

Now, using new optical measurements of the current universe from the international Dark Energy Survey (DES), these predictions can be tested independently. DES is an ongoing, five-year survey that aims to map 300 million galaxies and tens of thousands of galaxy clusters using a 570 megapixel camera to capture light from galaxies eight billion light-years away (see figure). The camera, one of the most powerful in existence, was built and tested at Fermilab in the US and is mounted on the 4 m Blanco telescope in Chile.

To measure how the clumps seen in the CMB evolved from the early universe into their current state, the DES collaboration first mapped the distribution of galaxies in the universe precisely. The researchers then produced detailed maps of the matter distribution using weak gravitational lensing, which measures small distortions of the optical image due to the mass between an observer and multiple sources. The galaxies observed by DES are elongated by only a few per cent due to lensing and, since galaxies are intrinsically elliptical, it is not possible to measure the lensing from individual galaxy measurements.

The first year of DES data, which includes measurements of 26 million galaxies, has allowed researchers to measure cosmological parameters such as the matter density with a precision comparable to those made using the CMB data. The matter-density parameter, which indicates the total fraction of matter in the universe, measured using optical light is found to be fully compatible with Planck data based on measurements of microwave radiation emitted around 13 billion years ago. Combining the measurements of Planck and DES places further constraints on this crucial parameter, indicating that only about 30% of the universe consists of matter while the rest consists of dark energy. The results are also compatible with other important cosmological parameters such as the fluctuation amplitude, which indicates the amplitude of the initial density fluctuations, and further constrain measurements of the Hubble constant and even the sum of the neutrino masses.

The DES results allow for a fully independent measurement of parameters initially derived using a map of the early universe. With the DES data sample set to grow from 26 million to 300 million galaxies, cosmological parameters will be measured with even higher precision and allow more detailed comparisons with the CMB data.



Map of dark matter made from gravitational lensing measurements of 26 million galaxies by the Dark Energy Survey, covering about 1/30th of the entire sky and spanning several billion light-years in extent. Red regions have more dark matter and blue regions less dark matter than average.

Further reading
T Abbott *et al.* 2017 FERMILAB-PUB-17-294-PPD, arXiv.org:1708.01530.

Picture of the month

This image from the Chandra X-Ray Observatory shows the Carina Nebula in X-rays (low-energy shown in red and the highest energy X-rays in blue). The nebula lies at an estimated distance of 6500–10,000 light years, measures approximately 200 light-years across, and is visible with binoculars toward the southern constellation of Carina. The Carina Nebula is a star-forming region in the Sagittarius-Carina arm of the Milky Way and Chandra has detected more than 14,000 stars in this region. As a star-forming region, the nebula hosts a large number of young and very bright star systems including WR25, which contains the brightest star in the Milky Way. The Trumpler 15 area, located in the northern part of the image, contains a deficit of bright X-ray sources indicating that several stars have recently died here. One object in this nebula that could end its life at any moment is Eta Carinae, a stellar system containing at least two stars with a combined luminosity greater than five million times that of the Sun. Eta Carinae erupted around 150 years ago when it became the second brightest star in the sky, and although it has since dimmed it is expected to become a supernova in the near future.

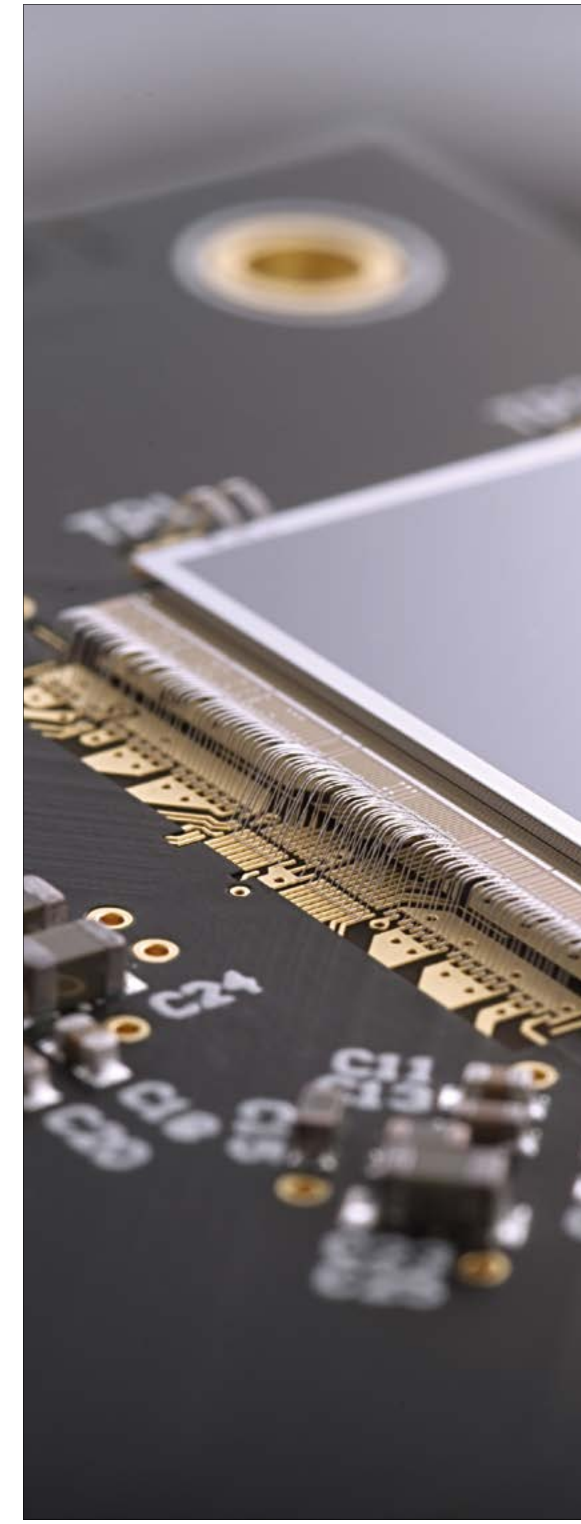
From the web to a start-up near you

Twenty years ago, CERN set up a reinforced structure dedicated to knowledge and technology transfer. This has led to hundreds of collaboration agreements and tens of new companies in sectors ranging from medical technology to aerospace.

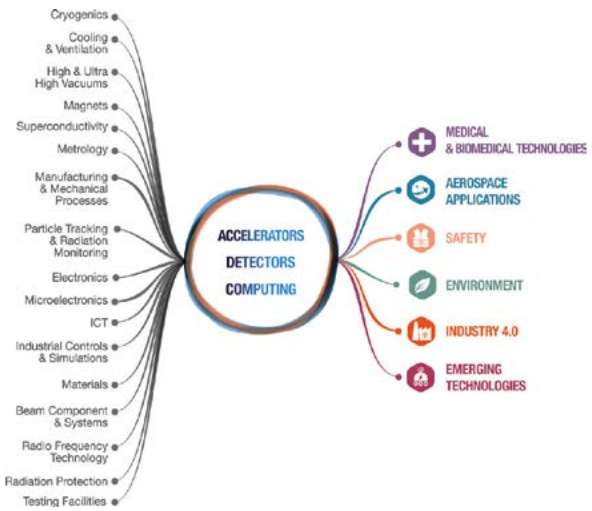
The core mission of CERN is fundamental research in particle physics. Yet, as a publicly funded laboratory, it also has a remit to ensure that its technology and expertise deliver prompt and tangible benefits to society wherever possible. Other physics-research laboratories and institutes were early adopters of CERN technologies, thanks to the highly collaborative nature of particle physics. Since its creation in 1954, CERN has also been active in transferring technology to industry, mainly through purchasing contracts or collaboration agreements. Through novel developments in the field of accelerator technologies and detectors, and more recently in computing and digital sciences, CERN technologies and know-how have contributed to applications in many fields, including the World Wide Web, invented at CERN by Tim Berners-Lee in 1989.

As its impact has broadened, in 1997 CERN set up a reinforced policy and team to support its knowledge- and technology-transfer activities. Twenty years later, these activities are still going strong. Some 18 start-up companies around the world are currently using CERN technology and CERN has developed a network of Business Incubation Centres (BICs) in nine different Member States. Its knowledge-transfer activities have impacted a wide range of fields, from medical and biomedical technologies to aerospace applications, safety, "industry 4.0" and the environment.

Maximising the societal impact of CERN technologies is a key aim for CERN's knowledge-transfer activities. To do this ▷



The Timepix3 chip is a multipurpose hybrid pixel detector developed within the Medipix3 collaboration, having applications in medical imaging, education, space dosimetry and materials analysis. (Image credit: M Brice/CERN.)



CERN's expertise builds broadly on three technical fields: accelerators, detectors and computing. Behind these three pillars of technology lie many threads of technology and human expertise that translate into positive impacts on society in many different fields. (Image credit: G Dorne/CERN.)

effectively, CERN has set up a thematic forum with delegates from all of its Member States and associate Member States. Regular meetings are held at CERN, and beginning this year there will also be forum meetings dedicated to medical applications – which is one of the most prominent examples of CERN's impact so far.

Technology for health

Early activities at CERN relating to medical applications date back to the 1970s, and have been triggered for the most part by individual initiatives. The multiwire proportional chamber conceived in 1968 by CERN physicist Georges Charpak not only opened a new era for particle physics and earned its inventor the 1992 Nobel Prize in Physics, but also found important X-ray and gamma-ray imaging applications in biology, radiology and nuclear medicine. Essential early work at CERN also contributed significantly to the development of advanced detectors and analysis techniques for positron emission tomography (PET). In particular, starting in 1975 with famous images of a mouse, CERN physicist David Townsend led important contributions to the reconstruction of PET images and to the development of 3D PET, in collaboration with the University of Geneva and the Geneva Cantonal Hospital.

After these individual efforts, in the 1990s CERN witnessed the first collaborative endeavours in medical applications. The Crystal Clear and Medipix collaborations started to explore the feasibility of developing technologies used in the LHC detectors – scintillating crystals and hybrid silicon pixel detectors, respectively – for possible medical applications, such as PET and X-ray imaging. At the same time, the Proton Ion Medical Machine Study (PIMMS) was initiated at CERN, with the aim of producing a synchrotron design optimised for treating cancer patients with protons and carbon ions. The initial design was improved by the TERA Foundation, and finally evolved into the machine built for the CNAO treatment centre in Italy, with seminal contributions from INFN. Later on, MedAustron in Austria built its treatment centre starting from the CNAO design. Beyond the initial design study, CERN contributed to the realisation of the CNAO and MedAustron treatment centres, in particular with expertise in accelerators and magnets and with training of personnel.

For the past 50 years, CERN has hosted the ISOLDE facility dedicated to the production of a large variety of radioactive ion beams for different experiments in the fields of nuclear and atomic physics, solid-state physics, materials science and life sciences. Over 1200 radioisotopes from more than 70 chemical elements have been made available for fundamental and applied research, including in the medical field. A particular highlight was the demonstration in 2012 of the efficiency of terbium-149, one of the lightest alpha emitters, for treatment at the level of single cancer cells. The growing worldwide interest in novel isotopes suitable for theragnostics, namely the possibility to perform both imaging and treatment at the same time, has motivated an extension of ISOLDE called CERN-MEDICIS (Medical Isotopes Collected from ISOLDE). This new facility will produce, as of this autumn, innovative isotopes for performing medical research at collaborating institutes (*CERN Courier* October 2016 p28).

Today, activities pertinent to medical applications are happening in all areas of CERN, with some compelling examples highlighted in the panel opposite. In June 2017, CERN Council approved a document setting out the "Strategy and framework applicable to knowledge transfer by CERN for the benefit of medical applications".

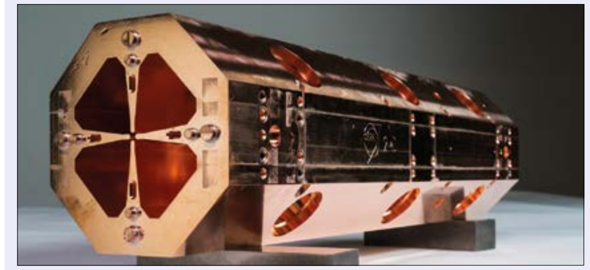
Aiming high

Aerospace and particle physics might not at first seem obvious partners. However, both fields have to deal with radiation and other extreme environments, posing stringent technological requirements that are often similar. CERN operates testing facilities and develops qualification technologies for high-energy physics, which are useful for ground testing and qualification of flight equipment. This opportunity is particularly attractive for miniaturised satellites called CubeSats that typically use commercial off-the-shelf components for their electronics, since radiation qualification according to standard procedures is expensive and time-consuming. The CERN Latchup Experiment STudent sAtellite (CELESTA) intends to develop a CubeSat version of RadMon, a radiation monitor developed at CERN, and to prove that low-Earth orbit qualification can be performed in CERN's High energy AcceleRator Mixed field facility (CHARM). CELESTA is being developed in collaboration with the University of Montpellier and this year was selected by ESA's "Fly Your Satellite!" programme to be deployed in orbit in 2018 or 2019.

Magnesium diboride (MgB_2), the high-temperature superconductor that will be used for the innovative electrical transmission lines of the high-luminosity LHC, has also demonstrated its potential for future space missions. Within the framework of the European Space Radiation Superconducting Shield (SR2S) project, which aims to demonstrate the feasibility of using superconducting magnetic shielding technology to protect astronauts from cosmic radiation, CERN successfully tested ▷

Cutting-edge medical technologies under CERN's microscope

Novel designs for compact medical accelerators



The first brazed RFQ module for medical applications.

Thanks to cutting-edge studies on beam dynamics and radio-frequency technology, along with innovative construction techniques, teams at CERN have manufactured an innovative linear accelerator designed to be compact, modular, low-cost and suitable for medical applications. The accelerator is a radio-frequency quadrupole (RFQ) operating at a frequency of 750 MHz, which had never been achieved before, and capable of producing low-intensity beams of just a few microamps with no significant losses. The high-frequency RFQ capitalises on the skills and know-how developed at CERN while designing Linac 4, and is a perfect injector for the new generation of high-frequency compact linear accelerators being developed for hadron therapy.

Expertise in high-gradient accelerating structures gathered by the Compact Linear Collider (CLIC) group at CERN is also being applied to novel designs for hadron-therapy facilities, such as the cyclinac concept proposed by the TERA foundation, as well as the development of accelerators to boost the energy of medical cyclotrons to provide proton-imaging capabilities.

CERN's know-how in cryogenic systems is also interesting for modern superconducting medical accelerators, such as the compact cyclotron being developed by CIEMAT for on-site production in hospitals of isotopes for PET.

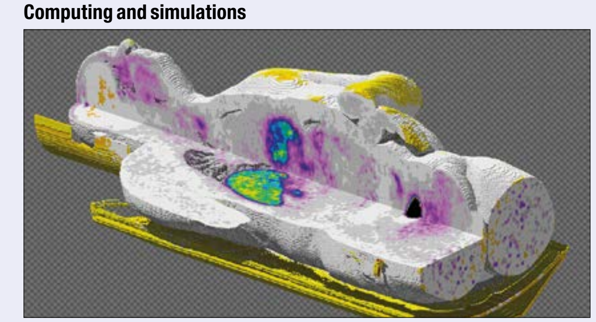
Detectors and medical imaging

Dense, precision-grown crystals for the CMS experiment.

Medipix3 is a CMOS pixel detector read-out chip designed to be connected to a segmented semiconductor sensor. Like its predecessor, Medipix2, it acts as a camera taking images based on the number of particles that hit the pixels when the electronic shutter is open. However, Medipix3 aims to go much further than Medipix2 by permitting colour imaging and dead-time free operation. Ten years ago, a member of the Medipix3 collaboration founded a company in New Zealand and obtained a licence to exploit the chip for spectral computed tomography imaging – X-Ray imaging in colour. The company's pre-clinical scanners enable researchers and clinicians to study biochemical and physiological processes in specimens and small animals. In a related development, the Timepix3 chip permits trigger-free particle tracking in a single semiconductor layer. Preliminary measurements using the previous generation of the chip point strongly to its potential for beam and dose monitoring in the hadron-therapy environment.

Since 1997, CERN's Crystal Clear collaboration (CCC) has been using its expertise in scintillators to develop and construct PET prototypes. Their first success was the ClearPET concept: the development of several prototypes has resulted in the commercialisation of a small-animal scanner with breakthrough performance and led to the first simultaneous PET/CT image of a mouse in 2015. Starting in 2002, the CCC started developing dedicated PET scanners for breast imaging, called ClearPEM, with two prototypes undergoing clinical trials. Recent CCC developments are focused on time-of-flight PET scanners for better image quality. Via the European FP7 project EndOTOFPET_US, CCC members are developing a novel bi-modal time-of-flight PET and an ultrasound endoscope prototype dedicated to early-stage detection of pancreatic and prostate cancer.

Computing and simulations



Monte Carlo simulations are essential for radiotherapy treatment planning.

Simulation codes initially developed for HEP, such as Geant4 and FLUKA, have also become crucial to modelling the effects of radiation on biological tissues for a variety of applications in the medical field. FLUKA is licensed to various companies in the medical field: in particular, FLUKA-based physics databases are at the core of the commercial treatment-planning systems (TPS) clinically used at HIT and CNAO, as well as of the TPS for carbon ions for MedAustron. Geant4 is adopted by thousands of users worldwide for applications in a variety of domains: examples of Geant4 extensions for use in the medical field are GATE, TOPAS and Geant4-DNA.

Computing tools, infrastructures and services developed for HEP have also great potential for applications in the medical field. CERN openlab has recently started two collaborative projects in this domain: BioDynaMo aims to design and build a cloud-based computing platform for rapid simulation of biological tissue dynamics, such as brain development; GeneROOT aims to use ROOT to analyse large genomics data sets, beginning with data from TwinsUK, the largest UK adult twins registry.

Image credits (from top): M Brice/CERN; DOI: 10.3389/fonc.2016.00116; P Ginter/CERN a prototype racetrack coil wound with a MgB_2 superconducting tape. Astronauts' exposure to space radiation is a major concern for future crewed missions to Mars and beyond. Monte Carlo codes such as FLUKA, initially jointly developed by CERN and INFN, and Geant4, developed and maintained by a worldwide collaboration with strong support from CERN since its conception, have been routinely used to study the radiation environment of past, recent, and future space missions. The TimePix detectors, which are USB-powered particle trackers based on the Medipix technology, are already used by NASA on board the International Space Station to accurately monitor radiation doses.

CERN's computing expertise is also finding applications in aerospace. To solve the challenge of sharing software and codes in big-data environments, researchers at CERN have developed a system called CernVM-FS (CERN Virtual Machine File Systems), which is currently used in high-energy physics experiments to distribute about 350 million files. The system is now also being used for Euclid, a European space mission that aims to study the nature of dark matter and dark energy, to deploy software in Euclid's nine science data centres.

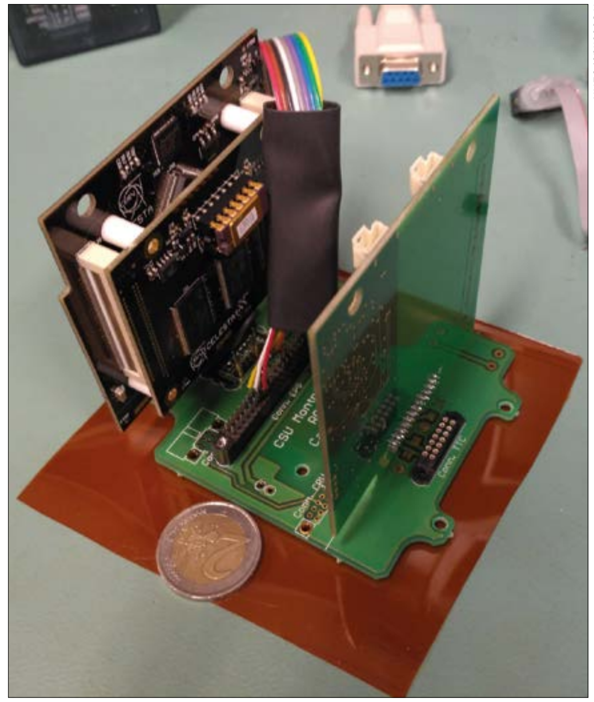
CERN technologies and know-how have found concrete applications in a variety of other fields. One of them is safety: CERN's unique working environment, which combines various types of radiation, extremely low temperatures, ultra-high magnetic fields and very high voltages, requires innovative solutions for detecting threats and preventing risks. An example is B-rad, a portable meter to ensure radiation safety in strong magnetic fields that was initially developed by CERN's radiation-protection group and fire brigade. With a financial contribution from the CERN Knowledge Transfer (KT) Fund, the product has been brought from lab prototype to finalised product in collaboration with an Italian company. Another example is Kryolize, a novel cryogenic safety software also supported by the CERN KT Fund. Six Kryolize licences have now been granted to other research laboratories, with potential application domains ranging from the food industry to cryogenic techniques in medicine.

CERN also taps into its technologies and creativity to address the challenge of a healthier and more sustainable planet. CERN's contribution in this area ranges from novel biochemical sensors for water safety through novel irrigation techniques for the most challenging agricultural environments. The innovative Non Evaporable Getter (NEG) technology developed to reach ultra-high-vacuum conditions in the LHC vacuum chambers, for example, was successfully used in other applications, including thermal solar panels.

MgB_2-based superconducting power cables could also offer significant power-transmission solutions for densely populated, high-load areas, and CERN is part of a consortium to build a prototype to demonstrate the feasibility of this concept.

Sensor technologies developed at CERN are also being used in drones.

Another buzz-worthy trend in industry is the so-called "industry 4.0", a push towards increasing automation and efficiency in manufacturing processes with connected sensors and machines, autonomous robots and big-data technology. CERN's accelerators, detectors and computing facilities naturally call for the use of the latest industry-4.0 technology, while the technological solutions to CERN's own challenges can be used in the automation industry. In the field of robotics, CERN has developed TIM (Train Inspection Monorail), a mini vehicle autonomously monitoring the 27 km-long LHC tunnel and moving along tracks suspended from the tunnel's ceiling, which can be programmed to perform real-time inspection missions. This innovation has already caught the eye of industry, in particular for autonomous monitoring of utilities infrastructure, such as underground water pipelines. Sensor technologies developed at CERN are also being used in drones, such as in the start-up Terabee, which uses them for aerial inspections and imaging services. Since their business was expanded to include CERN sensor development, the start-up won the prestigious first place in the automation category of Startup World at Automatica.



The CELESTA CubeSat payload module ready for radiation testing in CERN's CHARM facility.

R Secondo/CERN

Boosting KT in practice

One of the main challenges in the knowledge-transfer sphere is to make it as easy as possible for scientists and other specialists to turn their research into innovations, and CERN invests much effort in such activities. Launched in 2011, the CERN KT Fund bridges the gap between research and industry by awarding grants to projects proposed by CERN personnel where there is high potential for positive impact on society. Since its creation, 40 projects have been funded, each receiving grants with a value of CHF15–240 thousand over a period of one or several years. Among them were projects addressing thermal management in space applications, very large-scale software distribution, distributed optical-fibre sensors and long-term data preservation for digital libraries. In 2016, two European Commission funded projects, AIDA-2020 and ARIES, incorporated a proof-of-concept fund modelled on CERN's KT Fund.

Since the early days of technology transfer at CERN, one of the main focuses has been on knowledge transfer through people, especially early career scientists who work in industry after their contracts at CERN or who start their own company. Over the last 20 years, CERN has continued to build a general culture of entrepreneurship within the Organization through many different avenues. To assist entrepreneurs and small technology businesses in taking CERN technologies and expertise to the market, CERN has established a network of nine BICs throughout its Member States where companies can directly express their interest in adopting a CERN technology. The BIC managers provide office space, expertise, business support, access to local and national networks and support in accessing funding. There are currently 18 start-ups and spin-offs using CERN technologies in their business, with four joining BICs last year alone: Ross Robotics (exploiting software developed for production tasks at CERN); Innocryst (developing a system to identify and track gemstones); Colnec Health (using CERN's know-how in Grid middleware technology) and Camstech (novel electrochemical sensor technologies).

Every year since 2008, students from the School of Entrepreneurship (NSE) at the Norwegian University of Science and Technology (NTNU) spend a week at CERN to evaluate the business commercial potential of CERN technologies. Three of the students attending the CERN-NTNU screening week in 2012 started the spin-off TIND, which is based on the open-source software Invenio. TIND has now, among others, contracts to host Invenio for the UNESCO International Bureau of Education, the California Institute of Technology and the Max Planck institute for Extraterrestrial Physics.

Getting the next generation of scientists into the habit of thinking about their research in terms of impact is vital for knowledge transfer to thrive. In 2015, CERN launched a series of Entrepreneurship Meet-Ups (EM-Us) to foster entrepreneurship within the CERN community. Selected CERN and external entrepreneurship experts present their expertise at informal get-togethers and the events offer a good opportunity to network. In October this year, the EM-Us are celebrating their 50th event, with over 1000 attendees since the series was created, and a new informal "KT-clinic" service has been launched.

Many more interesting projects are in the pipeline. CERN's knowledge in superconducting technologies can be used in MRI and gantries for hadron therapy, while its skills in handling large amounts of data can benefit the health sector more widely. Detector technologies developed at CERN can be used in non-destructive testing techniques, while compact accelerators benefit the analysis of artworks. These are just some of the examples of new projects we are working on, and more initiatives will be started to meet the needs of industrial and research partners in CERN's Member States and associate Member States for the next 20 years and beyond.

A brief history of knowledge transfer at CERN

- **1954**: Since its creation, CERN has been active in knowledge and technology transfer, although with no formal structure.
- **1974 & 1983–1984**: Two external studies consider the economic impact of CERN contracts and find that it equates to around 3–3.5 times the contract value.
- **1987**: CERN's Annual Report incorporates the first dedicated section on technology-transfer activities.
- **1988**: The Industry and Technology Liaison Office (ITLO) is founded at CERN to stimulate interaction with industry, including through procurement.
- **June 1997**: With the support of Council, CERN sets up a reinforced structure for technology transfer.
- **November 1997**: The Basic Science and Technology Transfer: Means and Methods in the CERN Environment workshop helps to identify appropriate technology-transfer mechanisms.
- **1998**: CERN develops a series of reports on intellectual-property-rights protection practices that was endorsed by the finance committee.
- **1999**: First technology-transfer policy at CERN, with the new technology-transfer service replacing the ITLO and three main actions: to encourage the protection of intellectual-property rights for new technologies developed at CERN and the institutes participating in its scientific programme; to promote the training of young scientists in intellectual-property rights; and to promote entrepreneurship.
- **2001**: CERN begins to report on its technology-transfer activities annually to the CERN finance committee.
- **2008**: creation of HEPTECH, a technology-transfer network for high-energy physics.
- **2010**: CERN develops a new policy on the management of intellectual property in technology-transfer activities at CERN.
- **2014**: OECD publishes a report entitled "The Impacts of Large Research Infrastructures on Economic Innovation and on Society: Case studies at CERN", which praises innovation at CERN.
- **2016**: CERN featured as leader in World Intellectual Property Organisation (WIPO) Global Innovation Index.
- **2017**: CERN publishes new medical-applications strategy, works on a set of updated software and spin-off and patent policies, and launches a revamped knowledge-transfer website: kt.cern.

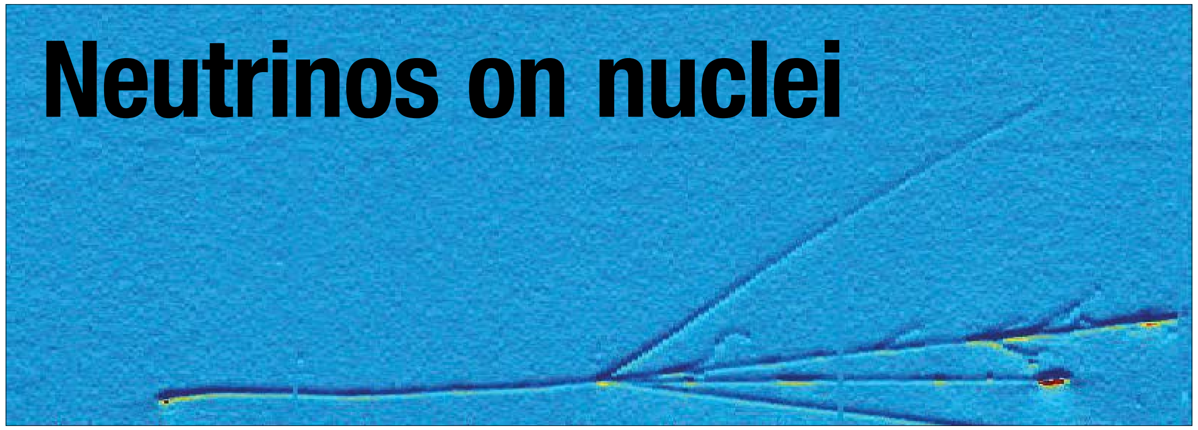
Résumé

Du web à des entreprises proches de vous

La recherche fondamentale en physique des particules constitue la mission principale du CERN. Toutefois, le CERN étant un laboratoire financé par des fonds publics, il doit également faire en sorte que, dans la mesure du possible, ses technologies et ses compétences apportent des bénéfices à la société. Il y a 20 ans, l'Organisation a intensifié ses efforts dans le domaine du transfert de connaissances et de technologies ; ceux-ci ont débouché sur des centaines d'accords de collaboration et des dizaines de nouvelles entreprises, dans des secteurs allant des technologies médicales à l'aérospatial.

Anais Rassat and **Manuela Cirilli**, CERN.

Neutrinos on nuclei



An event display from the ArgoNeuT experiment at Fermilab in which a small-scale liquid-argon time projection chamber was exposed to the NuMI neutrino beam in a similar fashion to the future DUNE experiment. The neutrino-interaction vertex is clear, with the backward-travelling proton to the left and exiting pions and a muon to the right.

Detailed modelling of the way neutrinos interact with nuclei is crucial if DUNE and other long-baseline neutrino experiments are to extract essential neutrino properties.

A major focus of experiments at the Large Hadron Collider (LHC) is to search for new phenomena that cannot be explained by the Standard Model of particle physics. In addition to sophisticated analysis routines, this requires detailed measurements of particle tracks and energy deposits produced in large detectors by the LHC's proton–proton collisions and, in particular, precise knowledge of the collision energy. The LHC's counter-rotating proton beams each carry an energy of 6.5 TeV and this quantity is known to a precision of about 0.1 per cent – a feat that requires enormous technical expertise and equipment.

So far, no clear signs of physics beyond the Standard Model (BSM) have been detected at the LHC or at other colliders where a precise knowledge of the beam energy is needed. Indeed, the only evidence for BSM physics has come from experiments in which the beam energy is known very poorly. In 1998, in work that would lead to the 2015 Nobel Prize in Physics, researchers discovered that neutrinos have mass and that, therefore, these elementary particles cannot be purely left-handed, as had been assumed by the Standard Model. The discovery came from the observation of oscillations of atmospheric and solar neutrinos. The energies of the latter are determined by various elementary processes in the Sun and cover a wide range from a few keV up to about 20 MeV.

Since then, dedicated "long-baseline" experiments have started to explore neutrino oscillations under controlled conditions by sending neutrino beams produced in accelerator labs to detectors located hundreds of kilometres away. The T2K experiment in Japan shoots a beam from JPARC into the Super-Kamiokande underground detector about 300 km away, while the NOvA experiment in the US aims a beam produced at Fermilab to an above-ground detector near the Canadian border about 800 km away. Finally, the international Deep Underground Neutrino Experiment (DUNE), for which prototype detectors are being assembled at CERN (see p5), will send a neutrino beam from Fermilab over a distance of 1300 km to a detector in the old Homestake gold mine in South Dakota. The targets in these experiments are all nuclei, rather than single protons, and the neutrino-beam energies range from a few 100 MeV to about 30 GeV.

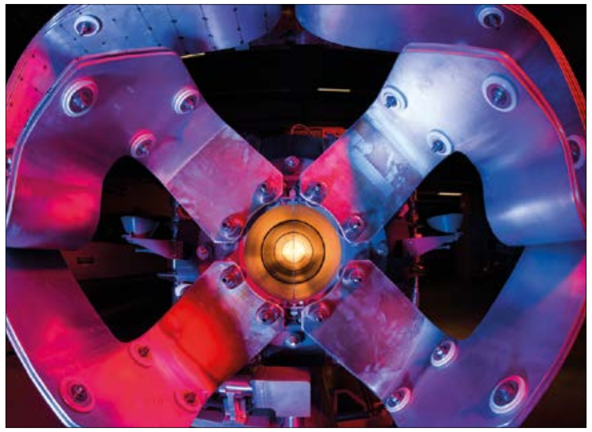
Such poor knowledge of neutrino-beam energies is no longer acceptable for the science that awaits us. All long-baseline experiments aim to determine crucial neutrino properties, namely: the neutrino mixing angles; the value of a CP-violating phase in the neutrino sector; and the so far unknown mass ordering of the three neutrino flavours. Extracting these parameters is only possible by knowing the incoming neutrino energies, and these have to be reconstructed from observations of the final state of a neutrino–nucleus reaction. This calls for Monte Carlo generators that, unlike those used in high-energy physics, not only describe elementary particle reactions and their decays but also reactions with the nuclear environment.

Beam-energy problem

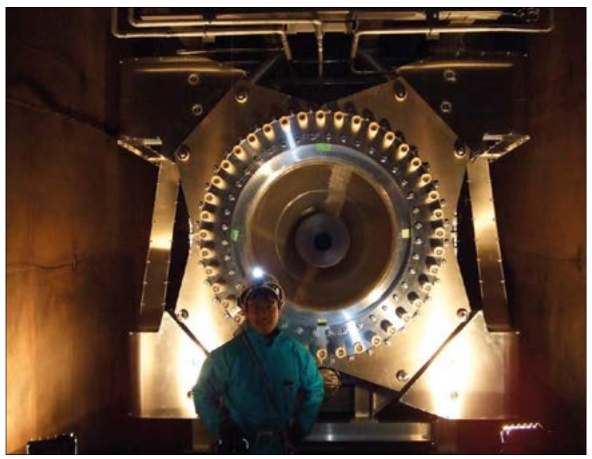
Neutrino beams have been produced for more than 50 years, famously allowing the discovery of the muon neutrino at Brookhaven National Laboratory in 1962. The difficulty in knowing the energy of a neutrino beam, as opposed to the situation at colliders such as the LHC, stems from the way the beams are produced. First, a high-current proton beam is fired into a thick target to produce many secondary particles such as charged pions and kaons, which are emitted in the forward direction. A device called a magnetic horn, invented by Simon van der Meer at CERN in 1961, then bundles the charged particles into a given direction as they decay into neutrinos and their corresponding charged leptons. Once the leptons have been removed by appropriate absorber materials, a neutrino beam emerges.

Whereas a particle beam in a high-energy accelerator has a ▷

Fermilab



J-PARC



The neutrino horn at Fermilab (top), which will send neturinos to the DUNE experiment, and for the T2K experiment in Japan (bottom).

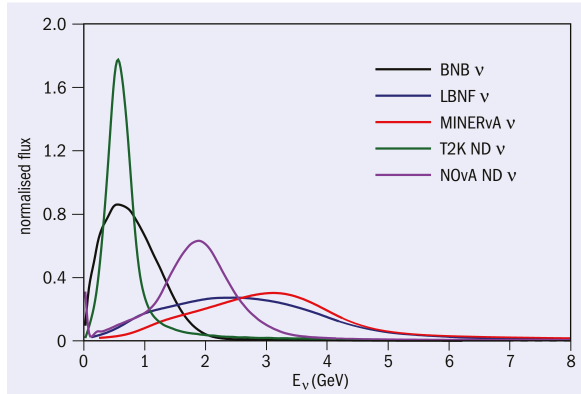


Fig. 1. Energy distributions for various neutrino experiments, all normalised to one.

T Leitner

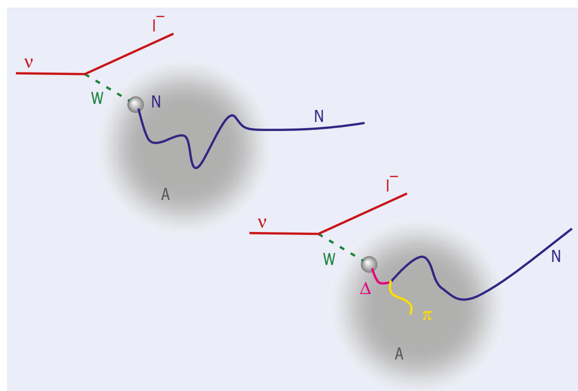


Fig. 2. True quasi-elastic scattering with subsequent re-scattering of the nucleon (upper left), and resonance excitation followed by decay into πN (the pion is reabsorbed).

diameter of about 10 μm, the width of the neutrino beam at its origin is determined by the dimensions of the horn, which is typically of the order of 1 m. Since the pions and kaons are produced with their own energy spectra, which have been measured by experiments such as HARP and NA61/SHINE at CERN, their two-body decays into a charged lepton and a neutrino lead to a broad neutrino-energy distribution. By the time a neutrino beam reaches a long-baseline detector, it may be as wide as a few kilometres and its energy is known only in broad ranges. For example, the beam envisaged for DUNE will have a distribution of energies with a maximum at about 2.5 GeV, with tails all the way down to 0 GeV on one side and 30 GeV on the other. While the high-energy tail may be small, the neutrino–nucleon cross-section in this region scales roughly linearly with the neutrino energy, so that even small tails contribute to interactions in the detector (figure 1).

The neutrino energy is a key parameter in the formula governing neutrino-oscillation probabilities and must be reconstructed on an event-by-event basis. In a "clean" two-body reaction such as $\nu_\mu + n \rightarrow \mu + p$, where a neutrino undergoes quasi-elastic (QE) scattering off a neutron at rest, the neutrino energy can be determined from the kinematics (energy and angle) of the outgoing muon alone. This kinematical or QE-based approach requires a sufficiently good detector to make sure that no inelastic excitations of the nucleon have taken place. Alternatively, the so-called calorimetric method measures the energies of all the outgoing particles to yield the incoming neutrino energy. Since both methods suffer from less-than-perfect detectors with limitations in acceptance and efficiency, the reconstructed energy may not be equal to the true energy and detector simulations are therefore essential.

A major additional complication comes about because all modern neutrino experiments use nuclear targets, such as water in T2K and argon in DUNE. Even assuming that the neutrino–nucleus interaction can be described as a superposition of quasi-free interactions of the neutrino with individual nucleons, the latter are bound and move with their Fermi motion. As a result, the kinematical method suffers because the initial-state neutron is no longer at rest but moves with a momentum of up to about 225 MeV, smearing the reconstructed neutrino energy around its true value by a few tens of MeV. Further-

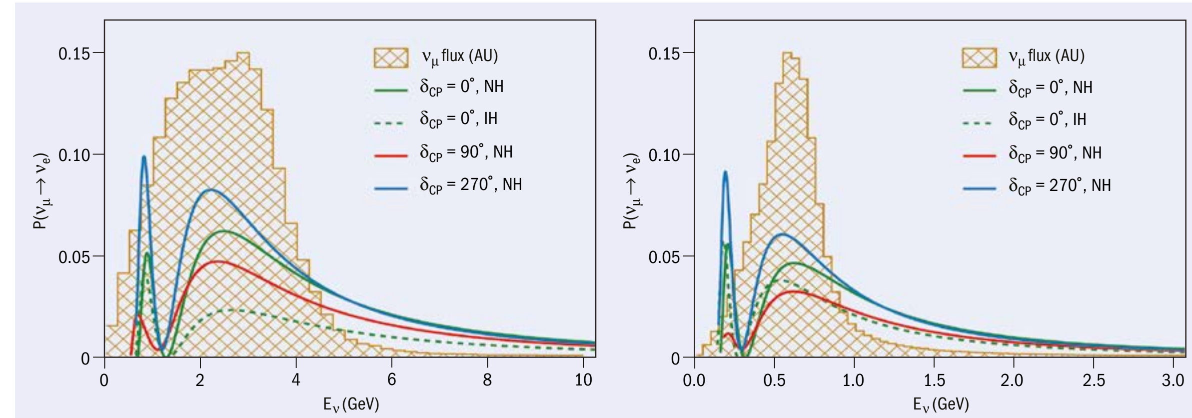


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Fig. 3. Sensitivity of the probability for oscillation from a muon neutrino into an electron neutrino to the CP-violating phase δ_{CP} for various angles, for the DUNE (left) and T2K (right) experiments. The cross-hatched areas give the energy distribution of the incoming neutrinos.

thermore, final-state interactions concerning the hadrons produced – both between themselves and with the nuclear environment of the detector – significantly complicate the energy reconstruction procedure. Even true initial QE events cannot be distinguished from events in which first a pion is produced and then is absorbed in the nuclear medium (figure 2), and the kinematical approach to energy reconstruction necessarily leads to a wrong neutrino energy.

The calorimetric method, on the other hand, suffers because detectors often do not see all particles at all energies. Here, the challenge to determine the neutrino energy is to "calculate backwards" from the final state, which is only partly known due to detector imperfections, to the incoming state of the reaction. One can gain an impression of how good this backwards calculation has to be by considering figure 3, which shows the sensitivity of the oscillation signal to changes in the CP-violating phase angle: for DUNE and T2K an accuracy of about 100 MeV and 50 MeV is required, respectively, to distinguish between the various curves showing the expected oscillation signal for different assumptions about the phase and the neutrino mass-ordering. At the same time, one sees that the oscillation maxima have to be determined within about 20% to be able to measure the phase and mass-ordering.

Detectors near and far

Neutrino physicists working on long-baseline experiments have long been aware of the problems in extracting the oscillation signal. The standard remedy is to build a detector not only at the oscillation distance (called the far detector, FD) but also one close to the neutrino production target (the near detector, ND). By dividing the event rates seen in the FD by those in the ND, the oscillation probability follows directly. The division also leads one to hope that uncertainties in our knowledge of cross-sections and reaction mechanisms cancel out, making the resulting probability less sensitive to uncertainties in the energy reconstruction. In practice, however, there are obstacles to such an approach. For instance, often the ND contains a different active material and has a different geometry to the FD, the latter simply because of the significant broadening of the neutrino beam with distance between the ND and the FD. Furthermore, due to the oscillation the energy spectrum of neutrinos is different in the ND than it is in the FD. It is therefore vital that we have a good understanding of the interactions in different target nuclei and energy regimes because the energy reconstruction has to be done separately both at the ND and the FD.

To place neutrino–nucleus reactions on a more solid empirical footing, neutrino researchers have started to measure the relevant cross-sections to a much higher accuracy than was possible at previous experiments such as CERN's NOMAD. MiniBooNE at Fermilab has provided the world's largest sample of charged-current events (QE-like reactions and pion production) on a target consisting of mineral oil, for example, and the experiment is now being followed by the nearby MicroBooNE, which uses an argon target. At higher energies, the MINERvA experiment (also at Fermilab) is dedicated to determining neutrino–nucleus cross-sections in an energy distribution that peaks at about 3.5 GeV and is thus close to that expected for DUNE. Cross-section measurements are also taking place in the NDs of T2K and NOvA, which are crucial to our understanding of neutrino–nucleus interactions and for benchmarking new neutrino generators.

Neutrino generators provide simulations of the entire neutrino–nucleus interaction, from the very first initial neutrino–nucleon interaction to the final state of many outgoing and interacting hadrons, and are needed to perform the backwards computation from the final state to the initial state. Such generators are also needed to estimate effects of detector acceptance and efficiency, similar to the role of GEANT in other nuclear and high-energy experiments. These generators should be able to describe all of the interactions over the full energy range of interest in a given experiment, and should ▷

We face a challenge that is completely new to high-energy physics experiments.

Neutrino–nucleus interactions

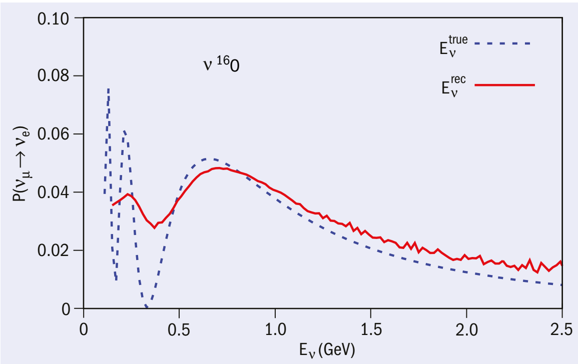


Fig. 4. Electron-neutrino appearance probability in the T2K flux with an oxygen target. The dashed and solid lines show the probability versus the true and kinematically reconstructed neutrino energy, respectively.

also be able to describe neutrino–nucleus and hadron–nucleus interactions involving different nuclei. Obviously, the generators should therefore be based on state-of-the-art nuclear physics, both for the nuclear structure and for the actual reaction process.

Presently used neutrino generators, such as NEUT or GENIE, deal with the final-state interactions by employing Monte Carlo cascade codes in which the nucleons move freely between collisions and nuclear-structure information is kept at a minimum. The challenge here is to deal correctly with questions such as relativity in many-body systems, nuclear potentials and possible in-medium changes of the hadronic interactions. Significant progress has been made recently in describing the structure of target nuclei and their excitations in so-called Green's function Monte Carlo theory. A similarly sophisticated approach to the hadronic final-state interactions is provided by the non-equilibrium Green's function method. This method, the foundations of which were written down half a century ago, is the only known way to describe high-multiplicity events while taking care of possible in-medium effects on the interaction rates and the off-shell transport between collisions. Only during the last two decades have numerical implementations of this quantum-kinetic transport theory become possible. A neutrino generator built on this method (GiBUU) has recently been used to explore the uncertainties that are inherent in the kinematical-energy reconstruction method for the very same process shown in figure 3, and the result of that study (figure 4) gives an idea of the errors inherent in such an energy reconstruction.

Generators that contain all the physics of neutrino–nucleus interactions are absolutely essential to get at the neutrino's intriguing properties in long-baseline experiments. The situation is comparable to that in experiments at the LHC and at the Relativistic Heavy Ion Collider at Brookhaven that study the quark–gluon plasma (QGP). Here, the existence and properties of the QGP can be inferred only by calculating backwards from the final-state observations with "normal" hadrons to the hot and dense collision zone with gluons and quarks. Without a full knowledge of the neutrino–nucleus interactions the neutrino energy in current and future long-baseline neutrino experiments cannot be reliably reconstructed. Thus, generators for neutrino experiments should clearly be of the same quality as the corresponding experimental apparatus. This is where the expertise and methods of nuclear physicists are needed in experiments with neutrino beams.

A natural test bed for these generators is provided by data from electron–nucleus reactions. These test the vector part of the neutrino–nucleus interaction and thus constitute a mandatory test for any generator. Experiments with electrons at JLAB are presently in a planning stage. Since the energy reconstruction has to start from the final state of the reaction, the four-vectors of all final-state particles are needed for the backwards calculation to the initial state. Inclusive lepton–nucleus cross-sections, with no information on the final state, are therefore not sufficient.

Call to action

All of this has been realised only recently and there is now a growing community that tries to bring together experimental high-energy physicists that work on long-baseline experiments with nuclear theorists. There is a dedicated conference series called NUINT, in addition to meetings such as WIN or NUFACT, which now all have sessions on neutrino–nucleus interactions.

We face a challenge that is completely new to high-energy physics experiments: the reconstruction of the incoming energy from the final state requires a good description of the nuclear ground state, control of neutrino–nucleus interactions and, on top of all this, control of the final-state interactions of the hadrons when they cascade through the nucleus after the primary neutrino–nucleon interaction. Neutrino generators that fulfil all of these requirements can minimise the uncertainties in the energy reconstruction. They should therefore attract the same attention and support as the development of new equipment for long-baseline neutrino experiments, since their quality ultimately determines the precision of the extracted neutrino properties.

● Further reading

L Alvarez-Ruso *et al.* 2017 arXiv:1706.03621.
O Buss *et al.* 2012 *Phys. Rept.* **512** 1.
M Diwan *et al.* 2016 *Ann. Rev. Nucl. Part. Sci.* **66** 47.
U Mosel 2016 *Ann. Rev. Nucl. Part. Sci.* **66** 171.

Résumé

Neutrinos et noyaux

Pour découvrir les caractéristiques essentielles des neutrinos, les expériences neutrino longue distance telles que DUNE doivent disposer de schémas détaillés sur les interactions neutrinos-noyaux. Cet élément est entièrement nouveau pour les expériences de physique des hautes énergies traditionnelles ; il exige une bonne description de l'état nucléaire fondamental, la maîtrise des interactions neutrinos-noyaux et la maîtrise des interactions des hadrons dans l'état final. Disposer de générateurs de neutrinos remplissant ces exigences est donc essentiel pour une expérience neutrino longue distance, car leur qualité détermine avec quelle précision les propriétés des neutrinos sont observées.

Ulrich Mosel, Justus Liebig University Giessen, Germany.

CERN strengthens ties with South Asia

The first CERN South Asian High Energy Physics Instrumentation workshop demonstrated the vibrancy of research in the region and the opportunities for closer international collaboration.

Particle physics is evolving as a result of greater co-ordination and collaboration on a global scale. This goes hand in hand with CERN's policy of increased networking with organisations and institutions worldwide. In 2010, the CERN Council approved a radical shift in CERN's membership policy that opened full membership to non-European states, irrespective of their geographical location. At the same time, the Council introduced the status of associate membership to facilitate the accession of new members, including emerging countries outside of Europe, which might not command sufficient resources to sustain full membership (*CERN Courier* December 2014 p58). Interest in membership and associate membership of CERN continues to grow (*CERN Courier* January 2017 p5).

CERN's geographical enlargement policy offers clear opportunities to reinforce the long-term aspirations of the high-energy physics community. Enlargement is not an aim in itself. Rather, the focus is on strengthening relations with countries that can bring scientific and technological expertise to CERN and, in return, allow countries with developing particle-physics communities to build capacity. Presently, CERN has 22 Member States, seven associate Member States, and six states and organisations with observer status. From the South Asia region, Pakistan and India have recently become associate members. International Co-operation Agreements (ICAs) have been signed with Bangladesh, Nepal and Sri Lanka.

The first CERN South Asian High Energy Physics Instrumentation (SAHEPI) workshop on detector technology and applications, held on 20–21 June at Nepal's Kathmandu University, Dhulikhel, brought together physicists and policy makers from the South Asia region and Mauritius. Representatives from Afghanistan, Bangladesh, Bhutan, India, the Maldives, Mauritius, Nepal, Pakistan and Sri Lanka were invited to attend. At least one senior scientist and one student from each country participated, making a total of about 70 participants, more than half of whom were students (representatives from the Maldives and Bhutan were not able to attend due to other commitments).

The aim of the workshop was to bring together representatives from CERN and South Asia countries to strengthen the scientific co-operation between the Organization and the South Asia region. The workshop also provided the opportunity for countries to establish new contacts within the region, with the objective of initiating new intra-regional co-operation in high-energy physics

All image credits: R Adhikari

Top: Students preparing for the poster session (left) and CERN's Emmanuel Tsesmelis addressing the workshop. Middle: Nepalese students welcoming participants at the registration desk, and participants of the SAHEPI workshop. Bottom: head of the Sri Lankan delegation, WGD Dharmaratna of the University of Ruhuna; and Archana Sharma and Emmanuel Tsesmelis with members of the local community and CERN's director for international relations, Charlotte Warakaulle.

and related technologies. The workshop was initiated as part of CERN's broader efforts to establish relations with regions, complementing relations with individual countries, and follows similar regional approaches in Latin America and South-east Asia.

Rewards of participation

Progress in particle physics relies on close collaboration between physicists, technicians, hardware and software engineers and industry, and both Member States and associate Member States enjoy opportunities to apply for staff and fellowship positions and bid for CERN contracts. Collaborating with CERN also trains young scientists and engineers in cutting-edge projects, giving them expertise that can be brought to their home nations, and offers great opportunities for educating the next generation through CERN's teacher programmes and others. Participation in CERN programmes has already fostered successful scientific collaborations in South Asia, where researchers have participated in many of CERN's pioneering activities and made a significant contribution to the construction of the LHC. Indeed, CERN's relations with South Asia feature strong partnerships dating back decades, particularly with India and Pakistan.

In 1994, CERN and the government of Pakistan signed an ICA concerning the development of scientific and technical co-operation in CERN's research. This agreement was followed by the signing of several protocols, and today Pakistan contributes to the ALICE and CMS experiments as well as to accelerator projects such as CLIC/CTF3 and Linac 4, making Pakistan a significant partner for CERN. Pakistan has also built various mechanical components for ATLAS and for the LHC, and made an important contribution to the LHC consolidation programme in 2013–2014. In July 2015 Pakistan became an associate Member State of CERN.

Given its long tradition and broad spectrum of co-operation with CERN since the 1970s, combined with the country's substantial scientific and technological potential, India applied for associate membership in 2015. In particular, in 1996 the Indian Atomic Energy Commission (AEC) agreed to take part in the construction of the LHC, and to contribute to the CMS and ALICE experiments and to the LHC Computing Grid with Tier-2 centres in Mumbai and Kolkata. In recognition of its contribution to the construction of the LHC, India was awarded observer status in 2002. The success of the partnership between CERN and the Indian Department of Atomic ▷

International relations

Image credits: J Ordan/CERN


On 16 June this year, the president of Mauritius, Ameenah Gurib-Fakim (left), and the president of Nepal, Bidya Devi Bhandari (right), independently visited CERN.

Energy (DAE) regarding the LHC has also led to co-operation on novel accelerator technologies through DAE's participation in CERN's Linac 4, Superconducting Proton Linac (SPL) and CTF3 projects, and CERN's contribution to DAE's programmes. India is also participating in the COMPASS, ISOLDE and n_TOF experiments. India became an associate Member State in January 2017.

Broader region

In the recent past, contacts have also been established with several other countries in the South Asia region. Collaboration between Sri Lanka and CERN has been ongoing for a number of years, following an expression of interest signed between the CMS collaboration and the University of Ruhuna in 2006. This saw the first CERN summer students from Sri Lanka and the first PhD student graduating in 2013. The conclusion of the ICA with the government of Sri Lanka in 2017, and the expected entry of a consortium of universities from Sri Lanka into the CMS collaboration, are important steps for growing the country's national high-energy physics capacity. Sri Lanka is moving towards membership of the CMS collaboration with an interest in contributing to the experiment's upgrade programme, driven initially by the University of Colombo and the University of Ruhuna.

Official contacts between CERN and Bangladesh were established in 2012 with the signing of an expression of interest. This provided an interim framework to enable scientists, engineers and students from universities and research institutes of Bangladesh to further develop their professional training, in particular through participation in CERN's scientific and training programmes. In 2014 CERN and Bangladesh signed an ICA, and the first Bangladesh–CERN school on particle physics was held at the University of Dhaka that year. Bangladesh is currently participating in the ALICE experiment as an associate member and working on physics analysis. There is a high potential for future development of the collaboration with CERN, through 39 public universities and 93 recognised universities and the high number of multidisciplinary research facilities of the Bangladesh Atomic Energy Commission.

Nepal has seven universities: Tribhuvan University (the largest and, until around 1990, the only university in the country); Kathmandu University; Pokhara University; Purbanchal University; Mahendra Sanskrit University; Far-western University; and the Agriculture and Forestry University. Tribhuvan and Kathmandu universities are considered to be best placed to develop scientific and technical co-operation with CERN, and collaborative activities are already under way between CERN and Nepal. Students from Nepal have been participating in the CERN summer-student programme for non-Member State nationals, and teachers from Nepal have taken part in the CERN high-school teachers programme. Several workshops on particle physics and related areas have been held at Tribhuven University and Kathmandu University, and an ICA between Nepal and CERN has recently been concluded.

Contacts with the physics communities of Afghanistan, Bhutan, the Maldives and Mauritius were established through the June workshop and will be pursued to explore ways and means to develop capacity in physics and related areas in these countries. The department of physics at the University of Kabul was established in 1942 and includes programmes for undergraduate and graduate studies in physics as well as student laboratories. The department of physics at the University of Mauritius includes research programmes in radioastronomy and applied radio frequency and it also operates the Mauritius Radio Telescope, while its undergraduate teaching programme includes courses in nuclear and elementary particle physics.

Moving forward

The nature of the national programmes in high-energy physics and related areas in these South Asian countries was the focus of discussions at the Kathmandu workshop. The aim was to identify synergies to establish stronger scientific collaboration across the region, such as promoting the exchange of researchers and students within the region. These efforts will help to build capacity, particularly in the countries with emerging high-energy physics programmes that face challenges in research infrastructure and university curricula.

The motivation and enthusiasm of the participants was palpable, and it was clear to see the efforts they put in for research and education. The proceedings of the workshop together with the identified strengths, weaknesses, opportunities and threats of the national programmes in high-energy physics and possibilities to strengthen the intra-regional co-operation will be presented to representatives of the governments from the participating countries with the objective to raise awareness at the highest political level.

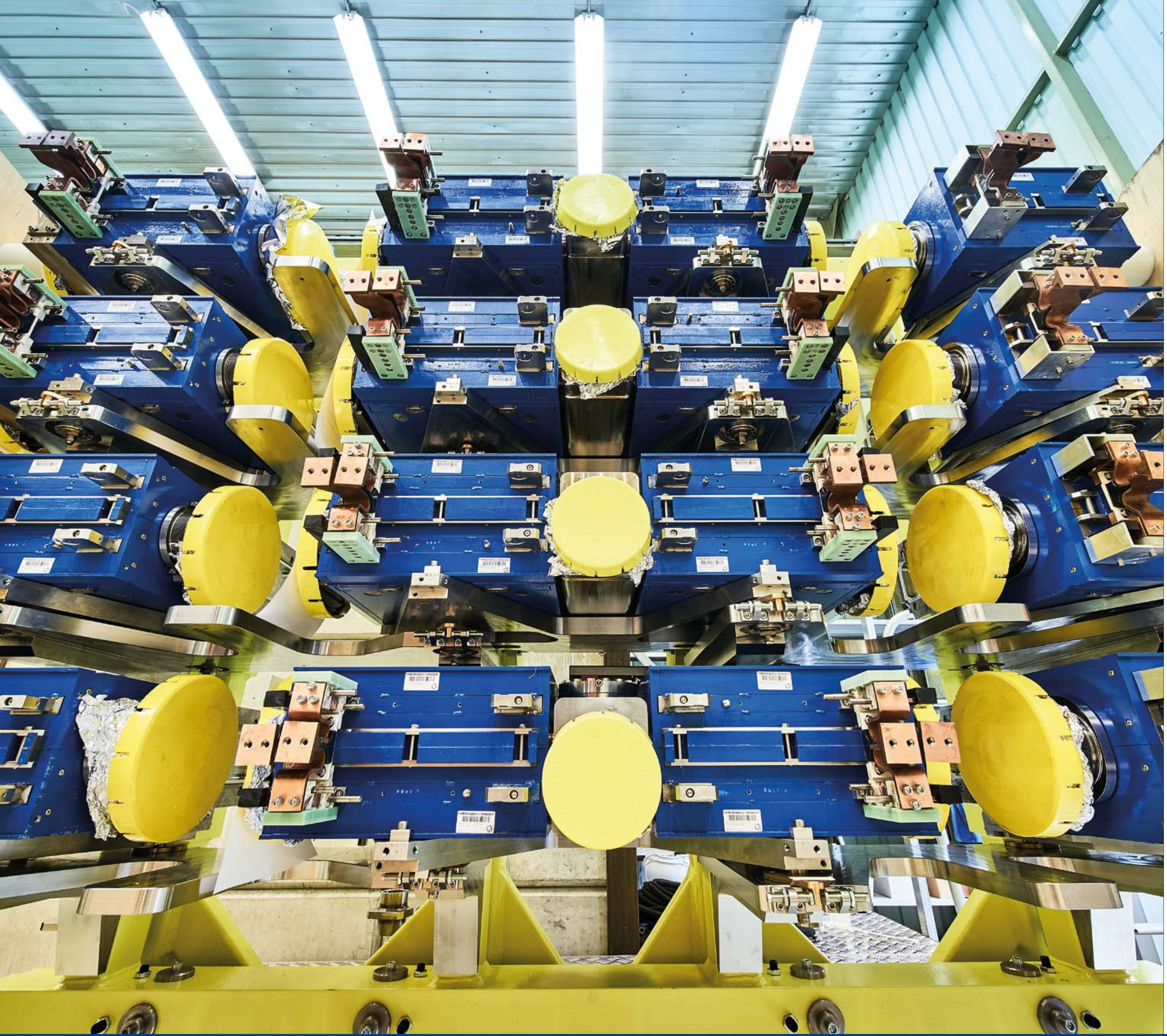
CERN will continue to engage with the region in an effort to build capacity in high-energy physics research and education and to facilitate collaboration with CERN. It was decided that due to the success of this workshop, discussions will continue in Sri Lanka in 2019.

Résumé

Le CERN renforce ses liens avec l'Asie du Sud

Le premier atelier CERN-Asie du Sud sur l'instrumentation pour la physique des particules, qui s'est déroulé en juin au Népal, a montré le dynamisme de la recherche dans la région et révélé des perspectives pour une collaboration internationale plus étroite avec le CERN et d'autres organisations.

Archana Sharma and **Emmanuel Tsesmelis**, CERN.



LHC Injectors Upgrade project

Injecting new life into the LHC

The LHC Injectors Upgrade project, initiated in 2010, is powering ahead to meet the daunting demands of the LHC's high-luminosity phase.

The Large Hadron Collider (LHC) is the most famous and powerful of all CERN's machines, colliding intense beams of protons at an energy of 13 TeV. But its success relies on a series of smaller machines in CERN's accelerator complex that serve it. The LHC's proton injectors have already been providing beams with characteristics exceeding the LHC's design specifications. This decisively contributed to the excellent performance of the 2010–2013 LHC physics operation and, since 2015, has allowed CERN to push the machine beyond its nominal beam performance.

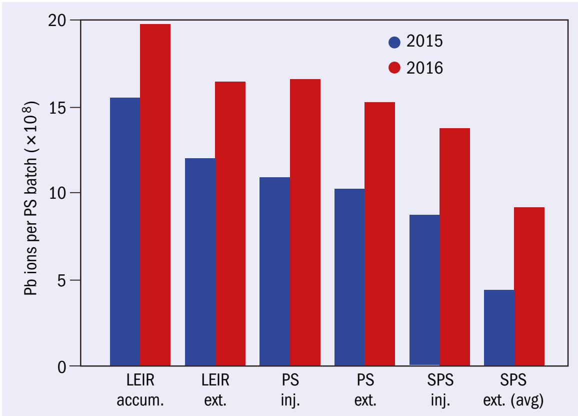
Built between 1959 and 1976, the CERN injector complex accelerates proton beams to a kinetic energy of 450 GeV. It does this via a succession of accelerators: a linear accelerator called Linac 2 followed by three synchrotrons – the Proton Synchrotron Booster (PSB), the Proton Synchrotron (PS) and the Super Proton Synchrotron (SPS). The complex also provides the LHC with ion beams, which are first accelerated through a linear accelerator called Linac 3 and the Low Energy Ion Ring (LEIR) synchrotron before being injected into the PS and the SPS. The CERN injectors, besides providing beams to the LHC, also serve a large number of fixed-target experiments at CERN – including the ISOLDE radioactive-beam facility and many others.

Part of the LHC's success lies in the flexibility of the injectors to produce various beam parameters, such as the intensity, the spacing between proton bunches and the total number of bunches in a bunch train. This was clearly illustrated in 2016 when the LHC reached peak luminosity values 40% higher than the design value of $10^{34}\,cm^{-2}\,s^{-1}$, although the number of bunches in the LHC was still about 27% below the maximum achievable. This gain was due to the production of a brighter beam with roughly the same intensity per bunch but in a beam envelope of just half the size.

Despite the excellent performance of today's injectors, the beams produced are not sufficient to meet the very demanding proton beam parameters specified by the high-luminosity upgrade of the LHC (HL-LHC). Indeed, as of 2025, the HL-LHC aims ▷

Pre-assembly of the future PSB injection region showing beam transfer magnets installed on a support structure. The adjacent dipole magnets, bus bars and tunnel wall are simulated by wooden structures and concrete blocks. (Image credit: J Ordan/CERN.)

H Bartosik & OP team



Ions	2016 achieved	LIU/HL-LHC
Bunch intensity (10^{8} ions/b)	2.2	1.9
Emittance (µm)	1.5	1.5
Number of bunches	548	1256

Protons	2016 achieved	LIU/HL-LHC
Bunch intensity (10^{11} p/b)	1.1	2.3
Emittance (µm)	1.5	2.1
Number of bunches	2208	2748

Fig. 1. Left: Increased number of lead ions at different stages in the ion injector chain as a result of LIU interventions. Above: LIU/HL-LHC lead ion (top) and proton (bottom) beam parameters at injection compared to 2016. The peak luminosity scales with the square of the intensity divided by the emittance.

to accumulate an integrated luminosity of around 250 fb^{-1} per year, to be compared with the 40 fb^{-1} achieved in 2016. For heavy-ion operations, the goals are just as challenging: with lead ions the objective is to obtain an integrated luminosity of 10 nb^{-1} during four runs starting from 2021 (compared to the 2015 achievement of less than 1 nb^{-1}). This has demanded a significant upgrade programme that is now being implemented.

Immense challenges

To prepare the CERN accelerator complex for the immense challenges of the HL-LHC, the LHC Injectors Upgrade project (LIU) was launched in 2010. In addition to enabling the necessary proton and ion injector chains to deliver beams of ions and protons required for the HL-LHC, the LIU project must ensure the reliable operation and lifetime of the injectors throughout the HL-LHC era, which is expected to last until around 2035. Hence, the LIU project is also tasked with replacing ageing equipment (such as power supplies, magnets and radio-frequency cavities) and improving radioprotection measures such as shielding and ventilation.

One of the first challenges faced by the LIU team members was to define the beam-performance limitations of all the accelerators in the injector chain and identify the actions needed to overcome them by the required amount. Significant machine and simulation studies were carried out over a period of years, while functional and engineering specifications were prepared to provide clear guidelines to the equipment groups. This was followed by the production of the first hardware prototype devices and their installation in the machines for testing and, where possible, early exploitation.

Significant progress has already been made concerning the production of ion beams. Thanks to the modifications in Linac 3 and LEIR implemented after 2015 and the intensive machine studies conducted within the LIU programme over the last three years, the excellent performance of the ion injector chain could be further improved in 2016 (figure 1). This enabled the recorded luminosity for the 2016 proton–lead run to exceed the target value by a factor of almost eight.

The LIU goals are in uncharted territory.

The main remaining challenges for the ion beams will be to more than double the number of bunches in the LHC through complex RF manipulations in the SPS known as "momentum slip stacking", as well as to guarantee continued and stable performance of the ion injector chain without constant expert monitoring.

Along the proton injector chain, the higher-intensity beams within a comparatively small beam envelope required by the HL-LHC can only be demonstrated after the installation of all the LIU equipment during Long Shutdown 2 (LS2) in 2019–2020. The main installations feature: a new injection region, a new main power supply and RF system in the PSB; a new injection region and RF system to stabilise the future beams in the PS; an upgraded main RF system; and the shielding of vacuum flanges together with partial coating of the beam chambers in order to stabilise future beams against parasitic electromagnetic interaction and electron clouds in the SPS. Beam instrumentation, protection devices and beam dumps also need to be upgraded in all the machines to match the new beam parameters. The baseline goals of the LIU project to meet the challenging HL-LHC requirements are summarised in the panel (final page of feature).

Execution phase

Having defined, designed and endorsed all of the baseline items during the last seven years, the LIU project is presently in its execution phase. New hardware is being produced, installed and tested in the different machines. Civil-engineering work is proceeding for the buildings that will host the new PSB main power supply and the upgraded SPS RF equipment, and to prepare the area in which the new SPS internal beam dump will be located.

The 86 m-long Linac 4, which will eventually replace Linac 2, is an essential component of the HL-LHC upgrade (see panel opposite). The machine, based on newly developed technology, became operational at the end of 2016 following the successful completion of acceleration tests at its nominal energy of 160 MeV. It is presently undergoing an important reliability run that will be instrumental to reach beams with characteristics matching the requirements of the LIU project and to achieve an operational availability higher than 95%, which is an essential level for the first link in the proton injector chain. On 26 October 2016, the first 160 MeV negative hydrogen-ion beam was successfully sent to the injection test stand, which operated until the beginning of April 2017 and demonstrated the correct functioning of this new and critical CERN injection system as well as of the related diagnostics and controls.

The PSB upgrade has mostly completed the equipment needed for the injection of negative hydrogen ions from Linac 4 into the PSB and is progressing with the 2 GeV energy upgrade of the PSB rings and extraction, with a planned installation date of 2019–2020 during LS2. On the beam-physics side, studies have mainly focused on the deployment of the new wideband RF system, commissioning of beam diagnostics and investigation of space-charge effects. During the 2016–2017 technical stop, the principal LIU-related activities were the removal of a large volume of obsolete cables and the installation of new beam instrumentation (e.g. a prototype transverse size measurement device and turn-by-turn orbit measurement systems). The unused cables, which had been individually identified and labelled beforehand, could be safely removed from the machine to allow cables for the new LIU equipment to be pulled.

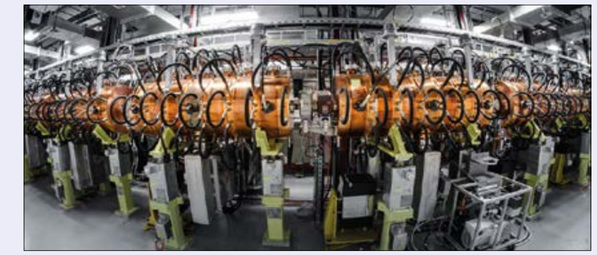
The procurement, construction, installation and testing of upgrade items for the PS is also progressing. Some hardware, such as new corrector magnets and power supplies, a newly developed beam gas-ionisation monitor and new injection vacuum chambers to remove aperture limitations, was already installed during past technical stops. Mitigating anticipated longitudinal beam instabilities in the PS is essential for achieving the LIU baseline beam parameters. This requires that the parasitic electromagnetic interaction of the beam with the multiple RF systems has to be reduced and a new feedback system has to be deployed to keep the beam stable. Beam-dynamics studies will determine the present intensity reach of the PS and identify any remaining needs to comfortably achieve the value required for the HL-LHC. Improved schemes of bunch rotation are also under investigation to better match the beam extracted from the PS to the SPS RF system and thus limit the beam losses at injection energy in the SPS.

In the SPS, the LIU deployment in the tunnel has begun in earnest, with the re-arrangement and improvement of the extraction kicker system, the start of civil engineering for the new beam-dump system in LSS5 and the shielding of vacuum flanges in 10 half-cells together with the amorphous carbon coating of the adjacent beam chambers (to mitigate against electron-cloud effects). In a notable first, eight dipole and 10 focusing quadrupole magnet chambers were amorphous carbon coated *in-situ* during the 2016–2017 technical stop, proving the industrialisation of this process (figure 2). The new overground RF building needed to accommodate the ▷

Linac 4 complete and preparing to serve the high-luminosity LHC

Inaugurated in May, Linac 4 is CERN's newest accelerator acquisition since the LHC and is key to increasing the luminosity delivered to the LHC. Linac 4 will send negative hydrogen ions with an energy of 160 MeV – more than three times the energy of its predecessor Linac 2 (which has been in service since 1978) – to the Proton Synchrotron Booster, which further accelerates the negative ions and removes the electrons. Almost 90 m long, it took nearly 10 years to build. After an extensive testing period that is already under way, Linac 4 will be connected to CERN's accelerator complex during the long technical shutdown in 2019–2020.

M Brice/CERN



M Van Gompel

Fig. 2. Set-up for in-situ coating of the beam chambers in the SPS dipoles with amorphous carbon, which is an efficient way to suppress the formation of electron clouds.

G Trad

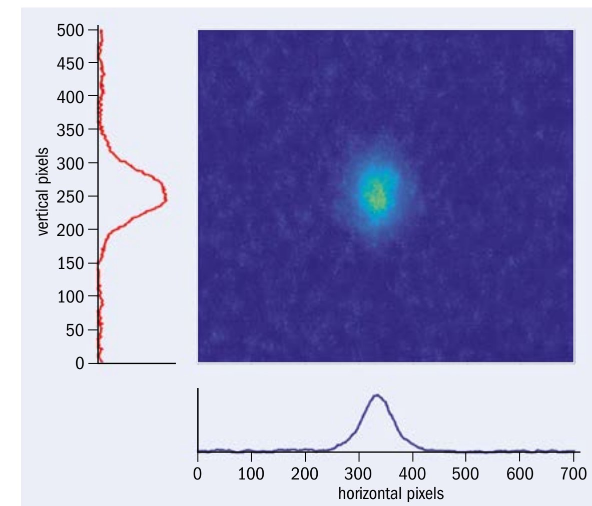
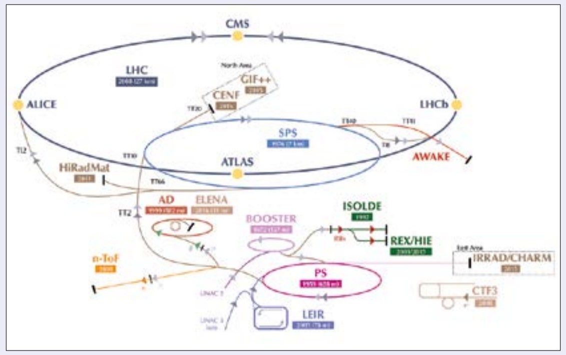


Fig. 3. Beam spot size (and its horizontal and vertical projections) acquired at high energy in the SPS with the beam synchrotron-radiation telescope. This tool enables beam-size measurements of long trains at high energy in the SPS and helps avoid the accidental injection of beams with poor transverse quality.

Overhauling CERN's accelerator complex



The demands of the high-luminosity LHC (HL-LHC) will see major changes across CERN's accelerator complex (above). The LHC Injectors Upgrade project is organised into five baseline work packages to boost the performance of the LHC injectors and match the challenging HL-LHC requirements:

- Improving ion source and low-energy transport in Linac 3, alleviating ion losses in LEIR and SPS, and implementing momentum slip stacking for ion beams in the SPS.
- Replacing Linac 2 with Linac 4 and using H^- charge-exchange injection into the PSB at the increased energy of 160 MeV.
- Raising the injection energy into the PS from the present 1.4 GeV to 2 GeV.
- Doubling the RF power, reducing the longitudinal impedance and mitigating the electron cloud in the SPS.
- Putting in place all of the other necessary equipment and operational upgrades across PSB, PS and SPS to make them capable of accelerating and manipulating higher-intensity/brightness beams (e.g. intercepting and dump devices, feedback systems, beam instrumentation and resonance compensation).

power amplifiers of the upgraded main RF system has been completed, while procurement and testing of the solid-state amplifiers has also commenced. The prototyping and engineering for the LIU beam-dump is in progress with the construction and installation of a new SPS beam-dump block, which will be able to cope with the higher beam intensities of the HL-LHC and minimise radiation issues.

Regarding diagnostics, the development of beam-size measurement devices based on flying wire, gas ionisation and synchrotron radiation, all of which are part of the LIU programme, is already providing meaningful results (figure 3) addressing the challenges of measuring the operating high-intensity and high-brightness beams with high precision. From the machine performance and beam dynamics side, measurements in 2015–2016 made with the very high intensities available from the PS meant that new regimes were probed in terms of electron-cloud instabilities, RF power and losses at injection. More studies are planned in 2017–2018 to clearly identify a path for the mitigation of the injection losses when operating with higher beam currents.

Looking forward to LS2

The success of LIU in delivering beams with the desired parameters is the key to achieving the HL-LHC luminosity target. Without the LIU beams, all of the other necessary HL-LHC developments – including high-field triplet magnets, crab cavities and new collimators – would only allow a fraction of the desired luminosity to be delivered to experiments.

Whenever possible, LIU installation work is taking place during CERN's regular year-end technical stops. But the great majority of the upgrade requires an extended machine stop and therefore will have to wait until LS2 for implementation. The duration of access to the different accelerators during LS2 is being defined and careful preparation is ongoing to manage the work on site, ensure safety and level the available resources among the different machines in the CERN accelerator complex. After all of the LIU upgrades are in place, beams will be commissioned with the newly installed systems. The LIU goals in terms of beam characteristics are, by definition, uncharted territory. Reaching them will require not only a high level of expertise, but also careful optimisation and extensive beam-physics and machine-development studies in all of CERN's accelerators.

Résumé

Injecter une nouvelle vie dans le LHC

Afin de préparer le complexe d'accélérateurs du CERN à l'immense défi que représente le LHC à haute luminosité, le projet LIU (Amélioration des injecteurs du LHC) a été lancé en 2010. Il doit permettre aux chaînes d'injection de produire les faisceaux de protons et d'ions nécessaires, mais il a aussi une autre mission : le remplacement des équipements vieillissants et l'amélioration des mesures de radioprotection telles que blindage et ventilation. Après les phases de définition, de conception et d'approbation de tous les éléments de base, qui se sont déroulées pendant les sept dernières années, le projet LIU est à présent dans la phase d'exécution. De nouveaux éléments matériels sont produits, installés et testés, tandis que des travaux de génie civil ont lieu en prévision des nouveaux bâtiments destinés à accueillir les équipements nécessaires.

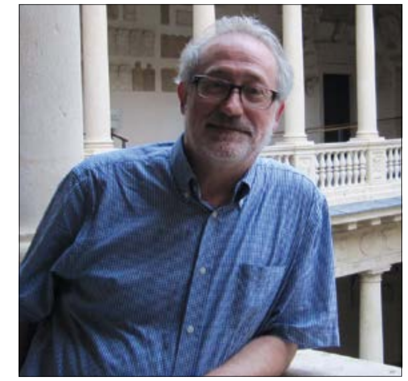
Malika Meddahi and **Giovanni Rumolo**, CERN.

Faces & Places

APPOINTMENTS

New spokesperson for GERDA

The international GERmanium Detector Array (GERDA) collaboration has appointed physicist Riccardo Brugnera of the University of Padua as its next spokesperson. The GERDA experiment operates at Italy's Gran Sasso National Laboratory with the aim of detecting neutrinoless double beta decay – which, if observed, would provide a strong indication that neutrinos and antineutrinos are identical (Majorana) particles. GERDA, which is based on high-purity germanium detectors with almost zero background contamination, entered its second phase at the end of 2015 and will run until the end of 2019. Brugnera will be in charge of the experiment for the next three years, taking over from Berhard Swingenheuer of the Max Planck Institut für Kernphysik in Heidelberg.



Riccardo Brugnera takes the lead in GERDA's search for Majorana neutrinos.

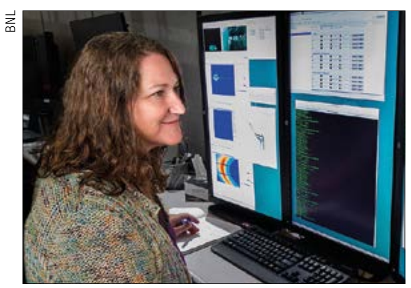
GERDA is one of several experiments vying to be first to spot neutrinoless double beta decay, many of which use large-volume detectors filled with a suitable isotope. CUORE at Gran Sasso uses tellurium, SNO+ in Canada uses heavy water, while KamLAND-Zen in Japan and EXO in the US use xenon, among others. Current half-life limits for neutrinoless double beta decay are above 10^{25} years, setting the bar for the next generation of experiments.

EVENTS

Brookhaven light source passes two years of user operations

The National Synchrotron Light Source II (NSLS-II) located at Brookhaven National Laboratory has completed two years of providing users with ultra-bright X-rays for experiments. During the past year, NSLS-II passed significant milestones in beam stability and reliability and is heading towards its operational current of 350 mA. There are currently 20 beamlines in operation but, when completed, NSLS-II will have as many as 60 beamlines. Eight new beamlines were added to NSLS-II during its second year, expanding the facility's reach into new fields of research.

BNL



Enzyme expert Joanna Krueger of the University of North Carolina was named the 1000th user at NSLS-II on June 28 this year.

In addition, NSLS-II's second year of operation saw several important results, including new cathode materials that could allow the mass production of sodium batteries and advances in our understanding of high-temperature superconductivity.

Physics at the festival frontier

Following a successful debut in 2016 that witnessed 4000 people happily packing themselves into a tent over three days in Charlton Park in the UK, CERN returned to the WOMAD festival this year with the Physics Pavilion. Featuring talks on theremins and electric guitars, the physics of the NA62 experiment, and the origins of creativity, the Pavilion was once again packed during a year with record attendance at the festival. Those who craved something more hands-on were not disappointed: The Lab, one of two new additions requested by the festival's management team, allowed participants to build their own cloud chamber, particle collision event, and more. CERN virtual-reality headsets created a queue at a third location called Outside at The Lab, where people eagerly explored the CMS experiment, and Devoxx4Kids allowed children to understand physics by modelling catapults in Minecraft code – perhaps inspiring the next generation of physics model-builders.

C Potter-Landua

A packed Physics Pavilion watches on as Bryson Gore reproduces some of his best science demonstrations.

The team behind the Physics Pavilion includes physicists from CERN, the UK Science and Technology Facilities Council, the Institute of Physics, and Lancaster University. The enthusiasm for science was clear to see, with proud parents asking for careers advice for their young Einsteins and Curies. "Can we visit?", "What if there are things smaller than quarks?", "What are you looking for now?" and "What can we use the Higgs boson for?" were just some of the tough questions asked by hungry minds at a festival that celebrates diversity and culture. With events like this, CERN and its partners are reaching out to a wide range of people, sharing knowledge and excitement, and showing that science is part of our common cultural heritage.

R Hahn, Fermilab

Eclipse captures world's attention

Hundreds of millions of people witnessed a rare total solar eclipse as it cast its shadow across 14 states in the US on 21 August – possibly the biggest audience for any natural event in history. CERN's James Gillies caught the spectacle while holidaying in Oregon, describing it as one of the most amazing things he's ever seen. "As you approach 100%, you see what looks like a tiny flash before totality begins, then the white corona appears. It brings it into focus that you are in a vast universe witnessing the alignment of three celestial bodies, one of which is your home. It only lasted for one minute and 16 seconds, but it left me wanting more!" The last time a total eclipse took place over the entirety of the US was 1918, and those who missed this summer's event will have to wait until April 2024 until the next total eclipse is visible from the US mainland.

(Above left) The clouds over Fermilab, located roughly 500 km north of the totality region, thinned just enough to capture this moment during the solar eclipse on the afternoon of 21 August.

EXHIBITIONS

Accelerating science in Turkey

H Aldemir

Accelerating Science has been touring the world since 2009 and to date has been seen by an estimated 800,000 people in 11 countries.

From 23 March to 23 July, Bilgi University in Istanbul was host to CERN's travelling exhibition "Accelerating Science". The exhibition was visited by more than 20,000 people, nearly half of which were group visits from high schools, and the event played an important role in raising public awareness about CERN and its objectives, with 141 press items on various Turkish media channels. Turkey became an associate member of CERN in 2015 and is strengthening its scientific, industrial and educational relations with CERN at an increasing pace.

CONFERENCES

Strangeness in quark matter

P van Dorp Van Vliet, Utrecht University

More than 210 participants attended 2017 Strangeness in Quark Matter in Utrecht.

The 17th edition of the International Conference on Strangeness in Quark Matter (SQM 2017) was held from 10 to 15 July at Utrecht University in the Netherlands. The SQM series focuses on new experimental and theoretical developments on the role of strangeness and heavy-flavour production in heavy-ion collisions, and in astrophysical phenomena related to strangeness. This year's SQM event attracted more than 210 participants from 25 countries, with 20% of attendees made up of female researchers. A two-day-long graduate school on the role of strangeness in heavy-ion collisions with 40 participants preceded the conference.

The scientific programme consisted of 53 invited plenary talks, 70 contributed parallel talks and a poster session. Three discussion sessions provided scope for the necessary debates on crucial observables to characterise strongly interacting matter at extreme conditions of high baryon density and high temperature and to define future possible directions. One of the discussions centred on the production of hadron resonances and their vital interactions in the partonic and hadronic phase, which provide evidence for an extended hadronic lifetime even in small collision systems and might affect other QGP observables. Moreover, future astrophysical consequences for SQM following the recent detection of gravitational waves were outlined: gravitational waves from relativistic neutron-star collisions can serve as cosmic messengers for the phase structure and equation-of-state of dense and strange matter, quite similar to the environment created in relativistic heavy-ion collisions.

Representatives from all major collaborations at CERN's Large Hadron Collider and Super Proton Synchrotron, Brookhaven's Relativistic Heavy Ion Collider (RHIC), and the Heavy Ion Synchrotron SIS at the GSI Helmholtz Centre in Germany made special efforts to release new data at this conference. Thanks to the excellent performance of these accelerator facilities, a wealth of new data on the production of strangeness and heavy quarks in nuclear collisions have become available.

New results

Among the highlights presented at the conference, the ALICE collaboration reported new results on strange and multi-strange hyperon production in heavy-ion collisions with a collision energy of 5.02 TeV per nucleon–nucleon pair and the first measurement of charm baryons (Λ_c and Ξ_c) in proton–proton and proton–lead collisions at the LHC. Furthermore, ALICE performed the most precise measurement of the hypertriton lifetime, an exotic nucleus composed of a proton, a neutron and a Λ particle. The CMS collaboration reported progress in understanding the different energy losses for charm and beauty quarks in the hot QCD medium, while the STAR experiment at RHIC gave an update on global Λ polarisation, which reveals that the curl of the fluid created at RHIC is much higher than that in any fluid ever observed. Enhanced strangeness production in small systems, as reported by the HADES, NA61/SHINE and ALICE collaborations, has also reignited the discussion surrounding strangeness production as a signature of the quark–gluon plasma.

Experimentally, the prospects in the field are good for future measurements at the Facility for Antiproton and Ion Research in Darmstadt (*CERN Courier* July/August 2017 p41), NICA at JINR Dubna, and at CERN (namely detector upgrades at the LHC during Long Shutdown 2 and the AFTER programme). On the theory side, new developments and vigorous research efforts are taking place towards a full understanding of strangeness production and open heavy-flavour dynamics in heavy-ion collisions. Global polarisation in heavy-ion collisions is also a current topic of interest, since it allows the study of the vorticity of the medium and the initial magnetic field.

Four young scientist prizes, sponsored by the *European Physical Journal A*, were awarded to the best parallel talk and poster presenters: Heidi Schuldes (Goethe University Frankfurt, Germany), Christian Bierlich (Lund University, Sweden), Yingru Xu (Duke University, US) and Vojtech Pacik (Niels Bohr Institute, Denmark).

The next edition of the SQM conference will take place in Bari, Italy, in June 2019.

● sqm2017.nl.

Rethinking dark matter in Vietnam

Dark matter poses an immense challenge for experts who are trying to detect it in a variety of ways, with all sorts of techniques, in every corner of the world. An event titled Exploring the Dark Universe, held from 23 to 29 July at the International Center of Interdisciplinary Science Education in Vietnam, witnessed an emerging buzz around new paradigms needed to discover the particles that dark matter is made of.

Running since 1993, the Rencontres du Vietnam is a series of conferences that builds on the success of the Rencontres de Moriond (which has been active since 1966) and Rencontres de Blois (since 1989). Exploring the Dark Universe was attended by 75 people from various institutes around the world and, more importantly, from various fields of physics across theory and experiment.

Limits on supersymmetric particles coming from the accelerator sector, particularly from the LHC, were discussed in the context of the cosmological constraints coming from satellite and ground observations, with theorists and phenomenologists presenting their best performing models. Neutrino experts from various experiments reviewed their different results and analyses, including information about non-atmospheric neutrinos from IceCube, while XENON 1T presented its latest results and constraints on direct

A Del Rosso

The ICISE centre in Quy Nhon, which has hosted the Rencontres du Vietnam since 2013.

dark-matter detection.

Popular puzzles got the audience's attention and triggered several discussions: FERMI's gamma-ray excess at GeV energies; the possible existence of sterile neutrinos; the long-standing seasonal modulation observed by DAMA-LIBRA; the AMS-02 antiproton anomalies; and the numerous secrets hiding in the galactic centre. In particular, there were lively exchanges about how easy, in principle, it would be to rule out cold dark matter made from axions and neutralinos by looking at the Einstein ring that is formed when the light source (a galaxy that we want to observe) is aligned with a lens (other galaxies) and the Earth (observer). By studying such rings, argued Carlos Frenk from the Institute for Computational Cosmology in Durham in the UK, one can predict how many dark-matter halos should be found in the galaxy and test warm- versus cold-dark-matter hypotheses against observations, although this requires complex analysis.

Another emerging idea is to get away from WIMPs (weakly interacting massive particles) and to focus instead on searches for light dark-matter particles, whose mass would be below 1 GeV. Such searches can be carried out in cosmic-ray experiments or at fixed-target experiments at low-energy electron accelerators, such as JLAB in the US or the secondary electron beamline from the SPS at CERN. Several experiments are reorienting their analyses to target this particular type of dark matter.

While the mystery of dark matter is clearly still with us, exploring the dark universe opened our eyes to new horizons in this fast-changing field. A keynote presentation by Nobel laureate Gerard 't Hooft of Utrecht University also described some of the latest thinking surrounding quantum black holes – another dark mystery that could lead us to a quantum theory of gravity. The next conference in the Rencontres du Vietnam series will be held in Moriond in 2019 and then again in Vietnam in 2021.

● vietnam.in2p3.fr/2017/dm.

Swiss and Austrian physical societies meet at CERN

This year's joint annual meeting of the Swiss and Austrian Physical Societies (SPS and ÖPG), in collaboration with the Swiss Institute of Particle Physics and the centre on Computational Design and Discovery of Novel Materials, took place from 21 to 25 August at CERN and at the Centre International de Conférences Genève (CiCG). With more than 500 registered participants and around 350 scientific contributions across eight parallel sessions, CERN could not host the full event on site. Thus, before moving to the CiCG, the first two days at CERN were dedicated to the executive board meetings of the participating societies and to plenary meetings, as well as offering guided tours to participants.

Physical societies play an important role

SPS

Discussions taking place during coffee breaks at CiCG.

in supporting physics in research, academia and industry. Opening the meeting, CERN's Director-General Fabiola Gianotti also highlighted the role played by CERN in uniting people across countries and cultures, while pushing technologies and training young scientists and engineers. Following addresses by the presidents of the SPS, ÖPG and the European Physical Society (EPS), plenary talks covered a variety of topics including an introduction to CERN and its accelerator complex. The importance of accelerators in other fields of science and industry was discussed, followed by a talk on gravitational waves and the latest news in the quest to find exoplanets. An evening lecture concluded the "CERN day" with a theoretical view on the outstanding questions in high-energy physics.

As non-profit organisations, national physical societies such as the SPS and ÖPG pursue non-economic interests. Through publications and by organising conferences and contributing to scientific events, the societies promote the transfer of knowledge within the scientific community and open a window to physics for all who are interested, especially young scientists. This helps to strengthen physicists' networks beyond their main research focus by enabling the exchange of knowledge across solid-state physics, plasma physics, particle physics, soft-matter physics, quantum optics, nanotechnology, bio- and medical physics, history, education, and also physics in industry. Such exchanges also increase the interaction between those working in "big science" and those active in table-top experiments.

The goal of physical societies is to provide a fruitful ground for physics to flourish in their home country as well as beyond borders via links with sister societies. Societies such as SPS and ÖPG actively support students from high school to university and beyond, for example through programmes such as the physics Olympiad and by awarding prizes sponsored by industry and academia to boost the careers of promising physicists. Whether student, professor or teacher, whether active in academia or in industry, physical societies address all who are interested in physics. Everyone can become a member and support the activities of their society to help physics to flourish further in their country.

By hosting this year's joint SPS and ÖPG annual meeting, CERN has contributed to promoting the role and relevance of national physical societies in their home countries as well as in our international community.

Updates from the Higgs sector

L Fayard

Participants at the July Higgs Hunting 2017 event.

The 8th Higgs Hunting workshop took place in Orsay and Paris on 24–26 July, attracting 120 physicists for lively discussions about recent results in the Higgs sector. The ATLAS and CMS collaborations presented results based on more than 35 fb^{-1} of data recorded at an energy of 13 TeV, which corresponds to almost all the data that has been taken so far at the LHC. The uncertainty on some measured properties of the Higgs boson discovered at CERN in 2012, such as the production cross-section, is already half the size with the 13 TeV data than it was after LHC Run 1 at 7 and 8 TeV – in particular in cases where the measurement is dominated by statistical errors.

Several searches for phenomena beyond the Standard Model, in particular for additional Higgs bosons, were presented. No significant excess was reported.

The next Higgs Hunting workshop will be in Orsay and Paris from 23 to 25 July 2018. A day will be devoted to future prospects at the high-luminosity LHC and possible future colliders, in view of the upcoming European Strategy for Particle Physics.

HASCO school reports from Göttingen

This year's Hadron Collider Physics Summer School (HASCO 2017) took place from 16 to 21 July in Göttingen, Germany, marking the sixth consecutive year that this dynamic and international school has been offered.

This year, 60 undergraduate students from 28 different institutes in 15 countries came together for a week to learn about hadron-collider physics. The 12 lecturers also came from a variety of institutes throughout the world. Students learnt about the foundations of quantum field theory and hadron-collider physics, particularly in the context of CERN's Large Hadron Collider.

At the HASCO school, numerous relevant research topics are discussed, among them quantum chromodynamics, jet physics, statistical methods in data analysis, accelerator physics, detector physics, top-quark physics, and searches for supersymmetry or exotic models and particles. This year's focus, however, was on the physics of the Higgs boson and the new challenges that come with the high-statistics data sample being recorded during the LHC's 13 TeV run.

All participating students passed the

C Nellist

The school not only provides lectures but allows students to make valuable connections at the outset of their careers.

written examination at the end of the school and received three European Credit Transfer System points, for which they can obtain course credits at their home universities. The students were inspired by the intense HASCO programme, which allowed them to engage deeply in the dynamic field of particle physics while being exposed to an international team where diverse ideas and creative solutions thrive.

● hasco.uni-goettingen.de.

Visits

J Ordan/CERN

State secretary for international financial matters in the Swiss Confederation, **Jörg Gasser**, came to CERN on 10 August. He visited the CERN Control Centre, ATLAS and the LHC superconducting magnet assembly hall before signing the guestbook (pictured).

J Ordan/CERN

Juraj Podhorsky, ambassador and permanent representative of the Slovak Republic to the United Nations in Geneva, visited CERN on the morning of 30 August during which he signed the guestbook and visited the synchrocyclotron.

H Chemli/CERN

On 24 August, **Farukh Amil**, ambassador and permanent representative of the Islamic Republic of Pakistan to the United Nations in Geneva, came to CERN. After signing the guestbook with CERN's Emmanuel Tsesmelis and Charlotte Warakaulle (pictured), he visited the Globe of Science and Innovation and the CMS experiment.

Obituaries

Bjørn Jacobsen 1961–2017

Norwegian delegate to the CERN Council and previous chair of the CERN Finance Committee, Bjørn Jacobsen, passed away on 13 June after a few months of illness.

Jacobsen studied physics at the University of Oslo, where he obtained his PhD in space physics in 1991. He spent the next 12 years in research in Norway and abroad, in particular two years at the European Space Research and Technology Centre (ESTEC) at Noordwijk in the Netherlands. In 2003 he joined the Research Council of Norway (RCN) where he worked until his death.

After joining the RCN he immediately connected with CERN, first as adviser to the Norwegian delegation and member of the Finance Committee. In 2008 he became Council delegate. He was chair of the Finance Committee 2011–2013 after having served as the committee's vice chair 2009–2010. In his capacity as chair of the Finance Committee he also served as chair of the CERN Standing Advisory Committee of Audits (SACA) and, more recently, he was member of the external review committee set up in April 2016 to optimise CERN's use of financial and human resources.

Research Council of Norway

Jacobson was Norwegian delegate to the CERN Council.

Jacobsen's leadership of the Finance Committee was conducted with calmness and wisdom. He managed to balance firmness and flexibility, and was met with general acclaim and respect. Always attentive and consensus-oriented, he smoothly steered the committee through waters that sometimes got rough, remaining thoughtful and balanced. He was a modest and conscientious person who treated everybody with respect and friendliness.

Bjørn played an important role as a source of contact and inspiration for the small Norwegian community at CERN and the high-energy physics community at large in Norway. He was also instrumental in our successful programme to recruit Norwegian technical students to CERN. His assistance to the Norwegian research community was not limited to high-energy physics, though. Bjørn co-ordinated the support of all physics programmes of the Research Council of Norway. More recently he served as a special adviser of the Norwegian contribution to large international infrastructure programmes such as the European Spallation Source, the European Incoherent Scatter Scientific Association and the Nordic Optical Telescope.

Bjørn Jacobsen was a colleague, science policy adviser and friend that we could not afford to lose. We will miss him dearly, and his memory will stay with us.

● *His colleagues and friends.*

Guido Petrucci 1926–2017

Guido Petrucci, one of the engineers who contributed to the reputation of CERN as a centre of technological excellence, passed away on 9 July after a long illness.

Born in Trieste on 27 September 1926, Guido obtained a degree in electro-technical engineering from the University of Rome in 1951 and was awarded a prize for the best thesis of the year. After working for a private electronics company in Rome, in 1954, together with other Italian engineers and physicists, Guido was recruited to CERN by Edoardo Amaldi, then CERN Secretary-General, to provide scientific and technical staff to the newly created European laboratory. Guido joined CERN in April 1954 and was assigned to the PS magnet group. Shortly afterwards, he joined the CERN–Manchester group involved in cosmic-ray experiments using a cloud chamber in a magnetic field at the Jungfraujoch laboratory (there were no accelerators yet in operation at CERN in those years). In this environment he developed a keen interest for physics that shaped his career. He became one of the leading engineers in the CERN physics research divisions and he always worked in close contact with physicists.

CERN

Guido Petrucci liked to define himself as an atypical engineer.

One of Guido's first contributions to the CERN research programme was the design of the magnet for the 2 m hydrogen bubble chamber, of which he supervised the construction and tests. At the same time, under the guidance of Simon van der Meer, he quickly learnt about beam optics and designed a large number of beam transport lines at the PS. Among his contributions, two are worth mentioning: a method to select particles in electrostatically separated beams using two small magnets, known as the Petrucci magnets; and the splitting of the slowly extracted proton beam to the PS East Area into three branches by means of a special magnet with two septa, providing a high degree of flexibility in the East Area beam layout.

In the second half of the 1960s Guido designed the storage ring for the third muon g-2 CERN experiment: a 7 m-radius ring consisting of 40 adjacent sector magnets excited by two all-around circular coils, with uniform magnetic field and focusing provided by a pulsed electrostatic quadrupole field. At the end of the experiment, in 1976, under Guido's leadership, this ring was transformed into a strong-focusing synchrotron for the Initial Cooling Experiment (ICE). The ICE experiment demonstrated that stochastic cooling, and later electron cooling, can increase the phase space density of 3.5 GeV/c antiprotons produced by the PS by the ▷

Faces & Places

required factor of around 10^8, marking a crucial step to the 1978 approval of SPS operation as a proton–antiproton collider.

Guido then worked on the design and construction of the magnet for the UA1 experiment, a dipole with a horizontal field of 0.7 T perpendicular to the beam axis over a volume of $3.5 \times 3.5 \times 7\,m^3$. The UA1 magnet had a second life during the 1990s as the magnetic spectrometer of the CERN NOMAD neutrino experiment, and it is now used in Japan as part of the near neutrino detector in the T2K experiment at J-PARC. After designing the UA1 magnet, Guido went on to design the magnetic structures of the ALEPH and DELPHI solenoidal spectrometers at LEP.

Guido retired from CERN in 1991, but he continued to work on a number of projects. These include: the ELETTRA synchrotron light source in Trieste, for which he contributed to the magnet design and construction; the hadron therapy project of the TERA foundation; the mechanical design of the tracking system for the KLOE experiment at the electron–positron collider DAΦNE in Frascati; and the PVLAS experiment at the Legnaro INFN laboratory to measure the birefringence of vacuum induced by a strong magnetic field, for which he contributed to the design of a system to rotate at a frequency of 0.3 Hz a 5 T superconducting dipole disconnected from its power supply.

Guido was an exceptionally bright engineer, always able to find simple and elegant solutions to difficult technical problems, and always willing to provide advice to his colleagues.

However, his personality was not only confined to his professional talents: he loved beauty in all its forms and had deep and broad cultural interests, covering all aspects of the arts, such as music (he held a piano diploma from the Rome conservatory), architecture and painting. He had many interests and was always willing to learn new subjects: a discussion with Guido was always an enriching experience, and he will be sorely missed by all those who had the privilege of being among his collaborators and friends.

● *His colleagues and friends.*

Peter Sonderegger 1935–2017

Peter Sonderegger was an all-round physicist.

Peter Sonderegger, an outstanding all-round physicist, left us on 9 August at the age of 82. Peter mastered theory as brightly as he did instrumentation, a domain in which he drove much innovation. His intellectual power and knowledge were amazing, allowing him to go boldly off the beaten track on several topics, and he also had linguistic and musical talents.

After graduating from ETH Zürich, he started at Saclay in around 1960 before coming to CERN and obtaining a permanent position in 1971. In the 1960s, a period dominated by Regge poles and duality, Peter's activities concerned two-body hadronic reactions, notably charge exchange and polarisation measurements. Responsible for physics at the Omega Spectrometer, he pursued them, mostly on backward and large transverse momentum scattering, including the search, until 1999, for narrow objects, as the elusive baryonium states. He also performed original searches and a systematic study of soft photons which, according to first principles, must appear in hadronic reactions. His rigour prevented him from drawing premature conclusions. In the 1976 Ω charm search, motivated by the J/ψ discovery, a presumed signal was reported that caused turmoil, threatening to disrupt the CERN programme, but Peter's clairvoyance (he was convinced that the signal was fake) and courage avoided that.

Drell–Yan dilepton production was one of his interests. The Omega Beam Dump, proposed in 1976, gave the first publication of the SPS era, measuring J/ψ production by various incident hadrons on hydrogen at 39.5 GeV/c. Peter's suggestion of an innovative centrality calorimeter allowed NA38 to pursue such studies with ions.

Peter devoted much work to HEP instrumentation, especially calorimetry, but also pixel detectors (such as NA60). He inspired a seminal 1983 NIM paper on fibre calorimetry, which led to lead scintillating fibre calorimetry and culminated with the "spaghetti" hadron calorimeter proposal of 1987. Highly active in the relevant R&D programmes (LAA, RD34), motivating and helping many young physicists, Peter was naturally involved in the genesis of the ATLAS tile calorimeter.

Peter developed an early interest and activity in heavy-ion physics, and was a major actor in a series of experiments from NA38 to NA60. He initiated the original and masterly performed NA51 experiment and is co-author of the ALICE LOI (1993) and of the 2003 LHC safety study group report, addressing supposedly dangerous events in LHC collisions. He played a major role in initiating the popularisation of particle physics, as in Aix Pop 1973, and, with José Gago, in the development of science in Portugal, including the field of astroparticle physics. NA38 was the first experiment with official Portuguese participation.

Besides being a great physicist, he was always asking what science could bring to society and was a courageous "alert launcher" about certain aspects of the nuclear industry. However, the greatest memory of Peter will be his extraordinary humanity – his moral rectitude, lack of personal ambition concerning career and honours, and great solicitude and generosity for others. It was a privilege and a pleasure to know Peter Sonderegger.

● *His friends.*

Recruitment

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Tel +44 (0)117 930 1264 Fax +44 (0)117 930 1178 E-mail sales@cerncourier.com
Please contact us for information about rates, colour options, publication dates and deadlines.

Announcement of CERN's 2018 Beamline for Schools competition

CERN is pleased to announce the 5th edition of the Beamline for Schools competition. Once again, in 2018, a fully equipped beamline will be made available at CERN for high-school students from around the world. What better way to learn about physics?

As in previous years, two teams will be invited to CERN to run their proposed experiments. The competition is open to teams of at least 5 students aged 16 and up with at least one adult supervisor.

BL4S is a unique science competition that can be used by teachers to complement or extend the physics classes. Our experience shows that it triggers a high level of motivation among students. Please help us to spread the word.

The deadline for proposals is the 31 March 2018. The winners will be announced in June and are expected to come to CERN in September 2018. Short-listed teams are offered smaller prizes. All participants will receive a certificate.

Dive into the fascinating world of particle physics and register already for 2018: http://beamline-for-schools.web.cern.ch/pre-registration-2018

beamline for schools

cern.ch/bl4s

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Bookshelf

Compiled by Virginia Greco, CERN

An Introduction to Gauge Theories

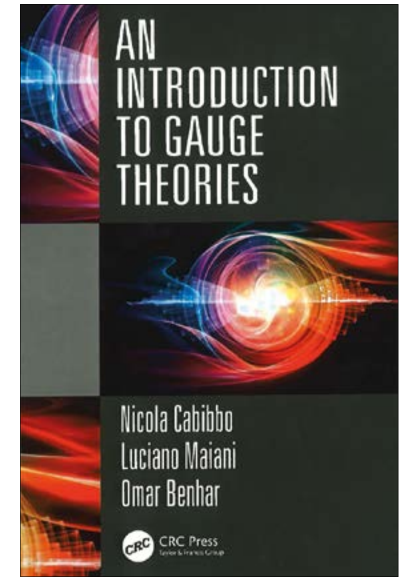
By N Cabibbo, L Maiani and O Benhar

CRC Press

There is always great excitement among the academic community when a new book by renowned scientists is published. Written by leading experts in particle physics, this book by Luciano Maiani and Omar Benhar, with contributions from the late Nicola Cabibbo, does not disappoint in this regard. Former CERN Director-General Maiani co-proposed the GIM mechanism, which is required to suppress flavour-changing neutral currents at the tree level and assumed the existence of a fourth quark that was discovered in 1974 at SLAC and BNL, while Cabibbo proposed a solution to the puzzle of electroweak decays of strange particles, which was later extended to give rise to the Cabibbo–Kobayashi–Maskawa mixing matrix. Omar Benhar, an INFN research director and professor at the University of Rome "La Sapienza", is expert in the theory of many-particle systems, the structure of compact stars and electroweak interactions of nuclei.

Their book is the third volume of a series dedicated to relativistic quantum mechanics, gauge theories and electroweak interactions, based on material taught to graduate students at the University of Rome over a period of several decades. Given that gauge theories are the basis of interactions between elementary particles, it is not surprising that there are many books about gauge theories already out there – among the best are those written by Paul Frampton, J R Aitchison and Anthony Hey, Chris Quigg, Ta-Pei Cheng and Ling-Fong Li. One might therefore think that it is hard to add something new to the field, but this book introduces the reader in a concise and elegant manner to a modern account of the fundamentals of renormalisation in quantum field theories and to the concepts underlying gauge theories.

Containing more than 300 pages organised in 20 chapters and several appendices, the book focuses mainly on quantum electrodynamics (QED), which – despite its simplicity and limitations – serves as the mould of a gauge theory and at the same time it has a high predictive power and numerous applications. The first part of this treatise deals with the quantisation of QED via the path-integral method, from basic to advanced concepts, followed by a brief discussion on the renormalisation of QED and some of its applications, such as bremsstrahlung, the Lamb shift, and the electron anomalous magnetic moment. The prediction of the latter is considered one of



the great achievements of QED.

In the second part of the book, the authors cover the renormalisation group equations of QED and introduce the quantisation of non-Abelian gauge theories, finishing with a proof of the asymptotic freedom of quantum chromodynamics. Afterwards, the concept of the running coupling constant is used to introduce a few ideas about grand unification. The final chapters are devoted to concepts related to the Standard Model of particle physics, such as the Higgs mechanism and the electroweak corrections to the muon anomalous magnetic moment. Finally, a few useful formulas and calculations are provided in several appendices.

Throughout the book the authors not only present the mathematical framework and cover basic and advanced concepts of the field, but also introduce several physical applications. The most recent discoveries in the field of particle physics are discussed. This is a book targeted at advanced students accustomed to mental challenges. A minor flaw is the lack of problems at the end of the chapters, which would offer students the possibility to apply the acquired knowledge, although the authors do encourage readers to complete a few demonstrations. This text will be very helpful for students and teachers interested in a treatment of the fundamentals of gauge theories via a concise and modern approach in the constantly changing world of particle physics.

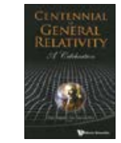
● *G Tavares-Velasco, BUAP.*

Books received

Centennial of General Relativity: A Celebration

By César Augusto Zen Vasconcellos (ed.)

World Scientific



In 1915 Albert Einstein presented to the Royal Prussian Academy of Sciences his theory of general relativity (GR), which represented a breakthrough in modern physics and became the foundation of our understanding of the universe at large. A century later, this elegant theory is still the basis of the current description of gravitation and a number of predictions derived from it have been confirmed in observations and experiments – most recently with the direct detection of gravitational waves.

This book celebrates the centenary of GR with a collection of 11 essays by different experts, which offer an overview of the theory and its numerous astrophysical and cosmological implications. After an introduction to GR, the Tolman–Oppenheimer–Volkoff equations describing the structure of relativistic compact stars are derived and their extension to deformed compact stellar objects presented. The book then moves to the so-called pc-GR theory, in which GR is algebraically extended to pseudo-complex co-ordinates in an attempt to get around singularities. Other topics covered are strange matter, in particular a conjecture that pulsar-like compact stars may be made of a condensed three-flavour quark state, and the use of a particular solution of the GR equations to construct multiple non-spherical cosmic structures.

Keeping the book contemporary, it also gives an overview of the most recent experimental results in particle physics and cosmology. Several contributions are devoted to the search for physics beyond the Standard Model at CERN, studies of cosmic objects and phenomena through gamma-ray lenses and, finally, to the recent detection of gravitational waves by the LIGO experiment.

Health Physics: Radiation-Generation Devices, Characteristics, and Hazards

By Joseph John Bevelacqua

Wiley-VCH

When developing technologies involving the use of nuclear material or ionisation radiation, a number of safety issues and potential risks have to be addressed. The author ▷

Bookshelf

of this book, a certified health physicist and an expert in radiation protection, discusses these emerging topics related to radiation-generating technologies and associated hazards.

The book opens with a brief overview of modern radiation-protection challenges, before delving into specific areas. First, the author discusses the nuclear-fuel cycle, analysing its steps and related issues such as reactors, new technologies for uranium enrichment and waste disposal. In the following section, he deals with nuclear accidents and radiological emergencies – making specific reference to the well-known disasters of Three Mile Island, Chernobyl and Fukushima Daiichi – and with the risk of terrorist events involving sabotage or the use of improvised nuclear weapons and devices.

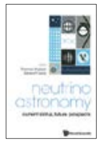
Today, nuclear material is also largely employed for medical imaging and therapies, thus a part of the book is devoted to these technologies and to the consequent increase of public radiation exposure. Finally, the last section focuses on regulatory issues, limitations and challenges.

Meant for upper-level undergraduate and graduate students of health-physics and engineering courses, the book would also be a useful reference for scientists and professionals working in radiation protection, fuel-cycle technology and nuclear medicine. More than 300 problems with solutions accompany the text and many appendices provide background information.

Neutrino Astronomy: Current Status, Future Prospects

By T Gaisser and A Karle (eds)

World Scientific



This review volume is motivated by the 2014 observation of a high-energy neutrino flux of extraterrestrial origin by the IceCube experiment at the South Pole. The energy of the events recorded ranges from 30 to 2000 TeV, with the latter marking the highest-energy neutrino interaction ever observed. The study of neutrinos originating from violent astrophysical sources enhances our knowledge not only of cosmological phenomena but also of neutrinos themselves.

This book gives an overview of the current status of research in the field and of existing and future neutrino observatories. The first group of chapters present the physics of potential sources of high-energy neutrinos, including gamma-ray bursts, active galactic nuclei, star-forming galaxies and sources in the Milky Way. A chapter is then dedicated to the measurements performed by IceCube, the results of which are discussed in terms of energy spectrum, flavour-ratio and arrival-direction isotropy. Following this, the results of two deep-sea neutrino experiments, ANTARES and Baikal, are presented.

After a brief discussion of other research topics in which the study of high-energy astrophysical neutrinos can play an important role, such as the quest for dark matter, the book examines the next generation of cosmic neutrino detectors. In particular, the future KM3NeT experiment, which will consist of a network of underwater telescopes located in the Mediterranean Sea, and IceCube-Gen2, characterised by unprecedented sensitivity and higher angular resolution compared to IceCube, are described.

Finally, a review of present and in-planning experiments aiming at detecting radio emissions from high-energy neutrino interactions concludes the volume.

Inside Story

The phys–math magnet in central Siberia

A unique physics and maths boarding school located in Siberia's famous Akademgorodok is still going strong after 55 years.

Image credits (clockwise from top): Phys-Math School; Phys-Math School; V Parkhomchuk

(Clockwise from top left) The Phys–Math School in Novosibirsk, Russia. Students deriving formulae during a class. Graduates of the 1963 class.

The Phys–Math School in Novosibirsk's Akademgorodok region began with the first all-Siberian physics and mathematics Olympiad in 1962. Well-known mathematician and creator of Akademgorodok, Mikhail Lavrentiev, called it an expedition for talent, and aimed to open a boarding school for the brightest students. Lavrentiev was convinced that future scientists should be trained from the school's bench, and his vision took hold.

While the organisation of the Phys–Math School continued over the autumn of 1962, its birthday is 23 January 1963 when the school officially opened its doors and the first lectures were delivered. These could hardly be called lectures in the usual sense – they were stories told by prominent scientists, interleaved with experimental demonstrations and discussions about the most recent scientific results. The teaching process in the school reproduced that of the neighbouring Novosibirsk State University, giving students a solid base for a scientific career, says Vladimir Shiltsev, who is a 1982 graduate of the Phys–Math School and now director of the accelerator-physics centre at Fermilab in the US.

Developing the teaching approaches in the first days of the Phys–Math School was a wonderful process of co-operation between scientists and pupils. The American Physical Society's 2016 Robert R Wilson Prize recipient and 1964 school graduate Vasili Parkhomchuk, famous for his work on electron cooling, recalls that the lectures in the school were taught by such professors as Gersh Budker (the founder of the Institute for Nuclear Physics, now called Budker INP). However, Parkhomchuk, who is now head of the lab at INP, says that, looking back at that time, the teachers did not know how to teach from a pedagogical point of view – they themselves were learning by doing. Professors and students "went to school" together, making it a magnificent collaboration and part of the brilliant programme envisaged by Lavrentiev and his colleagues.

The Siberian school, like CERN, is a magnet that attracts the brightest minds into science.

The history of the Novosibirsk Phys–Math School is connected to many developments in high-energy and accelerator physics, and also to CERN. These connections are via personalities – graduates of the school who became known or influenced the creation of facilities at CERN, like the LEAR electron cooling system, which was inspired by a visit by a CERN team to Novosibirsk and their interaction with the INP team. The Siberian school, like CERN, is a magnet that attracts the brightest minds into science. Mastering the ability of young scientists to find the key physical effects related to a complicated physical phenomena and then to make relevant estimations – such as working out in a few lines what happens when an asteroid strikes a planet – is one of the key training approaches of the school. Indeed, the school has served as a model for training in other parts of the world.

Today there are 500 pupils in the school, educated by more than 260 highly qualified teachers and academics. A total of 15,000 students have graduated since the school's creation, 25 per cent of which have PhDs and around 500 have DSc degrees. There are around 25 students per class and pupils can spend one, two or three of their last years of high school there. Competition is strong, with candidates first being invited to a summer school based on results of physics Olympiads and only the best performers are then invited to the Phys–Math School.

So congratulations to the Novosibirsk Phys–Math School at the start of the new academic year – a year in which it will celebrate its 55th birthday – and wishing it continued success for many years to come.

● *Andrei Seryi, John Adams Institute, UK.*

CERN Courier Archive: 1974

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

CERN News

Synchro-cyclotron has protons again

On 1 October the refurbished CERN synchro-cyclotron (now known as SC2) accelerated protons to the full energy of 600 MeV in a very successful start to its recommissioning.

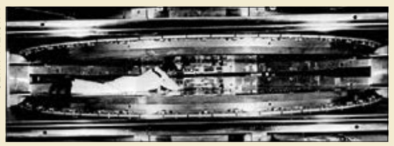
The SC was the first of CERN's machines, giving protons in 1957. By the early 1970s it had been overtaken, in terms of beam intensity, by several comparable machines in its energy range and had to confront the advent of the "meson factories" at Los Alamos, Vancouver and Villigen. To revitalize the experimental programme, by making higher intensity and better quality beams available, a series of improvements have been carried out during the past year.

Reassembly was completed in mid-September and acceleration tests began on the night of 29–30 September. Very quickly, protons were detected out to a radius of 30 cm where a thermocouple probe was located. The central region of the machine was behaving as predicted. On 1 October, it was decided to go for acceleration out to the full machine radius, less well-known territory. However, the beam spiralled out without any problem.

There has, of course, to be something which did not go as expected. The probe was pushed into the machine on a long cantilever arm so that it sat in the median plane at 30 cm radius. As it was withdrawn to greater radii, the signal disappeared despite two other detectors and the Dee voltage saying that all was well. This led to much head scratching.

The force of gravity is not highly regarded in high-energy physics labs because it seems to have very little effect on individual particles. It does, however, have considerable effect on a long arm close to Mother Earth. The arm bowed over to put the probe in the correct position at 30 cm radius but as it was shortened it lifted above the median plane and was no longer hit by protons. Alert men [*sic*] draw information even from the unexpected – the absence of the signal at larger radii said that the vertical spread of the beam was less than 1 cm, as had been hoped!

● Compiled from texts on pp334–335.



CERN 112.8.74

Final touches to the central region of the revamped 600 MeV synchro-cyclotron before it was buttoned up for the start of commissioning.

Los Alamos

LAMPF preparing for second assault

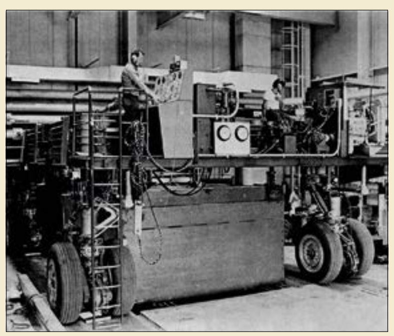
In a similar way to Fermilab having the first crack at a new energy range for high-energy physics experiments, the Los Alamos Meson Physics Facility, LAMPF, has the first crack at a new range of nuclear physics experiments.

The 800 MeV proton linear accelerator achieved full energy in June 1972, with the predominant advantage of intense particle beams for the study of nuclear phenomena. It has recently been joined as a "meson factory" by the cyclotron of the Swiss Institute for Nuclear Research, and the Canadian TRIUMF cyclotron is not far behind. Now LAMPF is preparing for a "great shutdown" in which the accelerator will be tidied up ready for a second assault with still higher intensities. The shutdown is scheduled to begin at the end of this year with the experimental programme opening up again around June 1975.

The machine's major features are: twin pre-injectors so that protons and negative hydrogen ions can be accelerated at the same time, a 100 MeV Alvarez type linac, subsequent acceleration to 800 MeV in a Los Alamos-invented side coupled cavity linac, and a switchyard dividing accelerated particles into a variety of experimental areas.

The main problems holding back the climb to higher currents are imprecise machine alignment, difficulties in achieving optimum settings for the r.f. amplitude and phase, and the inability, as yet, to handle much higher intensities in the experimental areas. They are all to receive attention during the great shutdown.

● Compiled from texts on pp349–351.

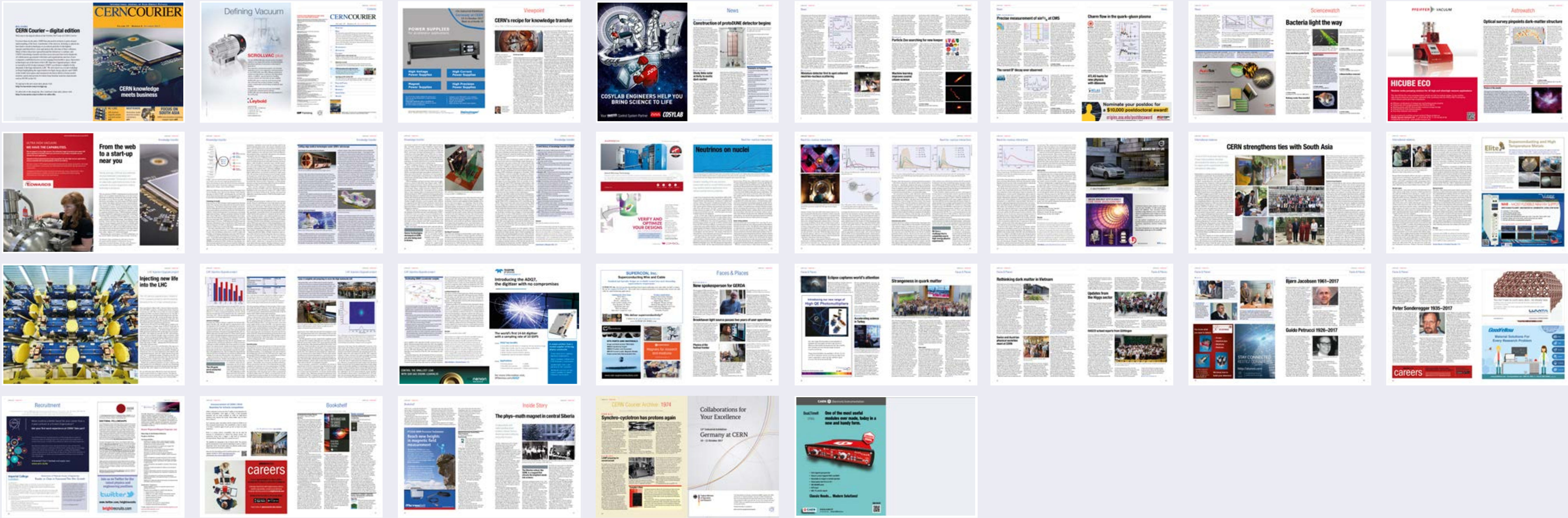


Servicing heavily irradiated components is a major problem at meson factories. LAMPF's answer is Merrimac. It rolls across the top of concrete shielding to the "hot" zone which needs attention, carrying a 200 tonne shielded box on its gantry. The box is lowered hydraulically through the opened up shielding and work can be carried out using a manipulator and a 5 tonne hoist. Aircraft buffs may recognize the B52 undercarriage.

Compiler's Note

Los Alamos became an Historic Site of the American Physical Society (APS) in July 2013, one in a series of APS scientific heritage sites launched in 2004. In 2011, inspired by this initiative, the European Physical Society (EPS) followed suit and the CERN Synchrocyclotron, now a feature on CERN's visitor circuits, was declared an EPS Historic Site in June 2014.

The first joint APS–EPS site, dedicated in September 2015, was the Einsteinhaus, the apartment in Bern, Switzerland, where Einstein lived from 1903 to 1905, and in November 2016 the Institute for Advanced Study in Princeton, at which Einstein was a faculty member, became the first joint site in the US.



CERNCOURIER

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Extracting neutrino properties from long-baseline neutrino experiments relies on modelling neutrino-nucleus interactions.

28 **CERN strengthens ties with South Asia**
A report from the first CERN South Asian High Energy Physics Instrumentation workshop held in June in Nepal.

32 **Injecting new life into the LHC**
The LHC Injectors Upgrade project, which will prepare CERN's accelerators for the the high-luminosity LHC, is in full swing.

39 **FACES & PLACES**

48 **RECRUITMENT**

51 **BOOKSHELF**

53 **INSIDE STORY**

54 **ARCHIVE**