WELCOME

CERN Courier – digital edition

Welcome to the December issue of *CERN Courier*.

Cosmic rays, being relatively easy to detect using inexpensive equipment, offer an ideal outreach and educational tool. Two projects described in this issue – Polarquest2018 and Clean2Antartica, which stem from existing networks of cosmic-ray detectors installed on high-school rooftops in Italy and the Netherlands – are taking cosmic-ray experiments to polar latitudes for the benefit of science, education and the environment. Going to other earthly extremes, this month's cover feature describes SNOLAB: the world's deepest cleanroom facility, located at a depth of 2 km and host to several neutrino and dark-matter experiments. On the machine front, Linac2 is switched off after 40 years of serving CERN with protons, while the world's first fourth-generation high-energy light source takes shape at the European Synchrotron Radiation Facility in Grenoble. Also featured in this issue is a call to address the gender imbalance in theoretical high-energy physics. Finally, in this last edition of *CERN Courier* in its current form, we report the results of our recent reader survey and set out the plans for the new-look magazine and website in 2019.

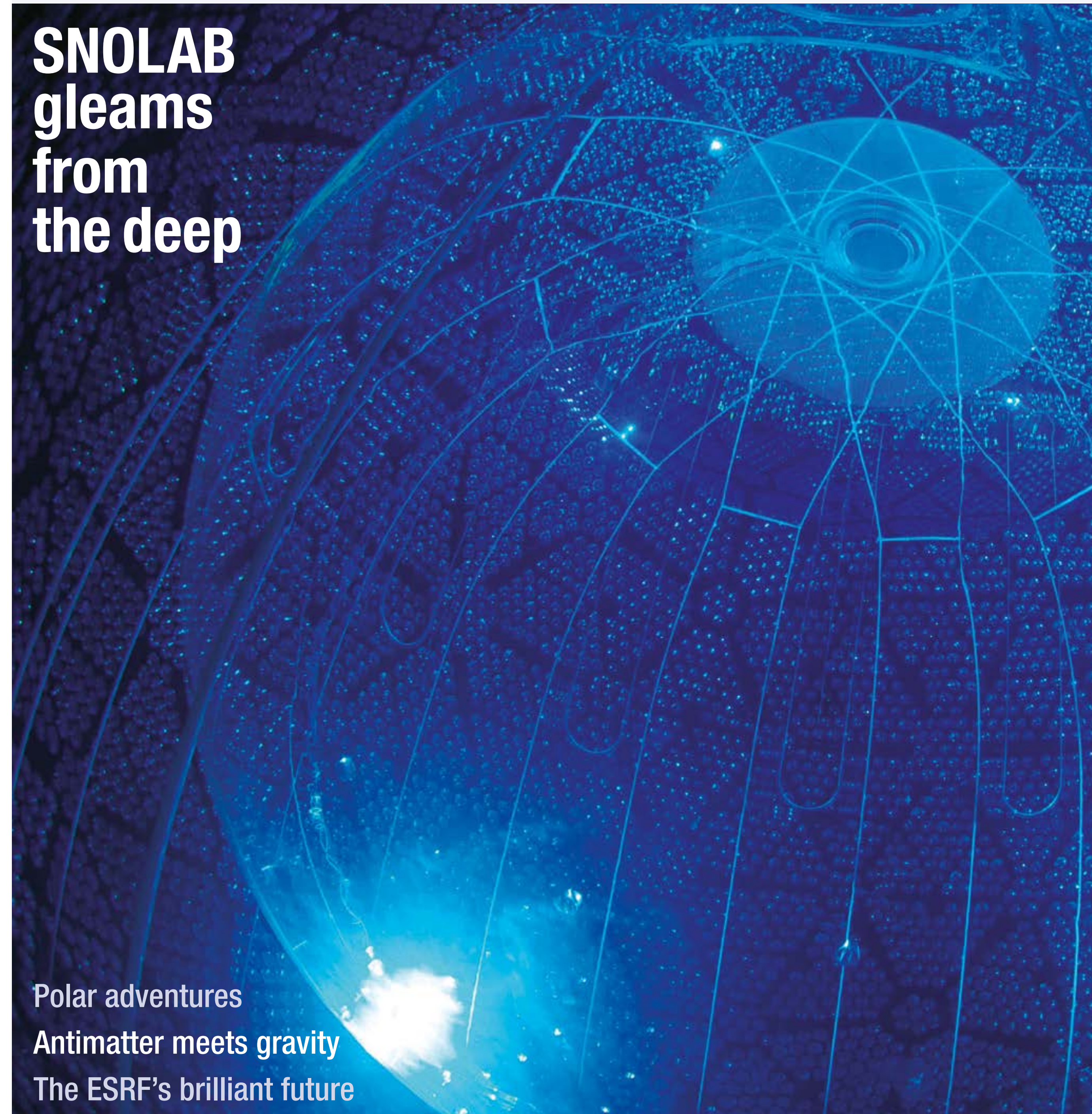
• The 2019 *CERN Courier* wall planner was sent to all subscribers, and can be obtained directly by getting in touch at **cern.courier@cern.ch**.

To sign up to the new-issue alert, please visit:
cerncourier.com/cws/sign-up.

To subscribe to the magazine, the e-mail new-issue alert, please visit:
cerncourier.com/cws/how-to-subscribe.

EDITOR: MATTHEW CHALMERS, CERN
DIGITAL EDITION CREATED BY DESIGN STUDIO/IOP PUBLISHING, UK

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERNCOURIER
VOLUME 58 NUMBER 10 DECEMBER 2018



Contents

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

CERN Courier is distributed to member-state governments, institutes and laboratories affiliated with CERN, and to their personnel. It is published monthly, except for January and August. The views expressed are not necessarily those of the CERN management.

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

Advisory board Peter Jenni, Christine Sutton, Claude Amsler, Philippe Bloch, Roger Forty, Mike Lamont, Matthew Mccullough

Laboratory correspondents:
Argonne National Laboratory (US) Tom LeCompte
Brookhaven National Laboratory (US) Achim Franz
Cornell University (US) D G Cassel
DESY Laboratory (Germany) Till Mundzeck
EMFCSC (Italy) Anna Cavallini
Enrico Fermi Centre (Italy) Guido Piragino
Fermi National Accelerator Laboratory (US) Kurt Riesselmann
Forschungszentrum Jülich (Germany) Markus Buescher
GSI Darmstadt (Germany) I Peter
IHEP, Beijing (China) Lijun Guo
IHEP, Serpukhov (Russia) Yu Ryabov
INFN (Italy) Antonella Varaschin
Jefferson Laboratory (US) Kandice Carter
JINR Dubna (Russia) B Starchenko
KEK National Laboratory (Japan) Hajime Hikino
Lawrence Berkeley Laboratory (US) Spencer Klein
Los Alamos National Laboratory (US) Rajan Gupta
NCSL (US) Ken Kingery
Nikhef (Netherlands) Robert Fleischer
Novosibirsk Institute (Russia) S Eidelman
Orsay Laboratory (France) Anne-Marie Lutz
PSI Laboratory (Switzerland) P-R Kettle
Saclay Laboratory (France) Elisabeth Locci
Science and Technology Facilities Council (UK) Jane Binks
SLAC National Accelerator Laboratory (US) Melinda Baker
TRIUMF Laboratory (Canada) Marcello Pavan

Produced for CERN by IOP Publishing Ltd
IOP Publishing Ltd, Temple Circus, Temple Way,
Bristol BS1 6HG, UK
Tel +44 (0)117 929 7481

Publisher Susan Curtis
Production editor Ruth Leopold
Technical illustrator Alison Tovey
Group advertising manager Chris Thomas
Advertisement production Katie Graham
Marketing & Circulation Laura Gillham

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

General distribution Courrier Adressage, CERN, 1211 Geneva 23, Switzerland
E-mail courrier-adressage@cern.ch
In certain countries, to request copies or to make address changes, contact:
China Ya'ou Jiang, Institute of High Energy Physics,
PO Box 918, Beijing 100049, People's Republic of China
E-mail jiangyo@mail.ihep.ac.cn
Germany Antje Brandes, DESY, Notkestr. 85, 22607 Hamburg, Germany
E-mail desypr@desy.de
UK Sian Giles, Science and Technology Facilities Council, Polaris House,
North Star Avenue, Swindon, SN2 1SZ
E-mail sian.giles@stfc.ac.uk
US/Canada Published by Cern Courier, 6N246 Willow Drive,
St Charles, IL 60175, US. Periodical postage paid in St Charles, IL, US
Fax 630 377 1569. E-mail creative_mailing@att.net
POSTMASTER: send address changes to Creative Mailing Services, PO Box 1147,
St Charles, IL 60174, US

Published by European Organization for Nuclear Research, CERN,
1211 Geneva 23, Switzerland
Tel +41 (0) 22 767 61 11. Telefax +41 (0) 22 767 65 55

Printed by Warners (Midlands) plc, Bourne, Lincolnshire, UK

 ISSN 0304-288X

IOP Publishing

CERNCOURIER

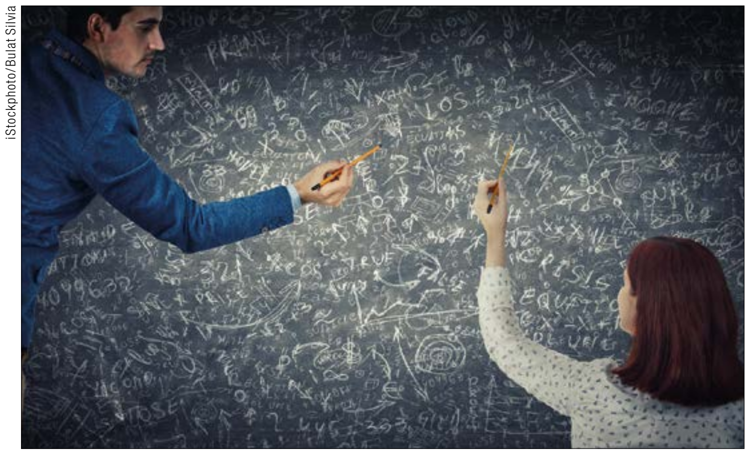
VOLUME 58 NUMBER 10 DECEMBER 2018

On the cover: The SNO+ neutrino detector at SNOLAB, p20. (Image credit: SNOLAB.)

Viewpoint

Fixing gender in theory

It is high time we addressed the low representation of women in high-energy theoretical physics.



iStockphoto/Bulat Silvia

A new initiative called GenHET aims to tackle the gender imbalance in high-energy theory.

By Marika Taylor

Improving the participation of under-represented groups in science is not just the right thing to do morally. Science benefits from a community that approaches problems in a variety of different ways, and there is evidence that teams with mixed perspectives increase productivity. Moreover, many countries face a skills gap that can only be addressed by training more scientists, drawing from a broader pool of talent that cannot reasonably exclude half the population.

In the high-energy theory (HET) community, where creativity and originality are so important, the problem is particularly acute. Many of the breakthroughs in theoretical physics have come from people who think "differently", yet the community does not acknowledge that being both mostly male and white encourages groupthink and lack of originality.

The gender imbalance in physics is well documented. Data from the American Physical Society and the UK Institute of Physics indicate that around 20% of the physics-research community is female, and the situation deteriorates significantly as one looks higher on the career ladder. By contrast, the percentage of females is higher in astronomy and the number of women at senior levels in astronomy has increased quite rapidly over the last decade.

However, research into gender in science often misses issues specific to particular disciplines such as HET. While many previous studies have explored challenges faced by women in physics, theory has not specifically been targeted, even though the representation of women is anomalously low.

In 2012, a group of string theorists in Europe launched a COST (European Cooperation in Science and Technology) action with a focus on gender in high-energy theory. Less than 10% of string theorists are female, and, worryingly, postdoc-application data in Europe show that the percentage of female early-career researchers has not changed significantly over the past 15 years.

The COST initiative enabled qualitative surveys and the collection of quantitative data. We found some evidence that women PhD students are less likely to continue onto postdoctoral positions than male ones, although further data are needed to confirm this point. The data also indicate that the percentage of women at senior levels (e.g. heads of institutes) is extremely low, less than 5%. Qualitative data raised issues specific to HET, including the need for mobility for many years before getting a permanent position and the long working hours, which are above average even for academics. A series of COST meetings also provided opportunities for women in string theory to network and to discuss the challenges that they face.

Following the conclusion of the COST action in 2017, women from the string theory community obtained support to continue the initiative, now broadened to the whole of the HET community. "GenHET" is a permanent working group hosted by the CERN theory department whose goals are to increase awareness of gender issues, improve the presence of women in decision-making roles, and provide networking, support and mentoring for women, particularly during their early career.

GenHET's first workshop on high-energy theory and gender was hosted by CERN in September, bringing together physicists, social scientists and diversity professionals (see p39). Further meetings are planned, and the GenHET group is also developing a web resource that will collect research and reports on gender and science, advertise activities and jobs, and offer advice on evidence-based practice for supporting women. GenHET aims to propose concrete actions, for example encouraging the community to implement codes of conduct at conferences, and all members of the HET community are welcome to join the group.

Diversity is about much more than gender: in the HET community, there is also under-representation of people of colour and LGBTQ+ researchers, as well as those who are disabled, carers, come from less privileged socio-economic backgrounds, and so on. GenHET will work in collaboration with networks focusing on other diversity characteristics to help improve this situation, turning the high-energy theory community into one that truly reflects all of society.

Marika Taylor is leader of the GenHET working group and is head of applied mathematics and theoretical physics at the University of Southampton, UK, with interests in string theory.

News

LHC REPORT

Machine powers down until 2021

The Large Hadron Collider's 2018 proton physics run came to an end on 24 October, having accumulated an impressive dataset. The integrated luminosity delivered to both the ATLAS and CMS experiments reached an average of around 66 fb^{-1} for the year, 10% higher than the target. This corresponds to around 5×10^{15} inelastic collisions per experiment. LHCb accumulated just under 2.5 fb^{-1}, while ALICE notched up 27 pb^{-1}. The high figures are due to excellent machine availability and an instantaneous luminosity that regularly touched $2 \times 10^{34}\,cm^{-2}s^{-1}$ in ATLAS and CMS – twice the nominal value.

The end of the proton run was followed by three and a half weeks of lead–lead collisions at a centre-of-mass energy of 5.02 TeV per colliding nucleon pair. Beginning on 5 November, this is the fourth lead–lead run since the collider began operation. During the last run of this type in 2015, the luminosity achieved was more than three and a half times higher than the LHC's design luminosity, and the goals for 2018 are even more ambitious. Lead ions were also collided with protons in the LHC back in 2016.

This year's shut-down marks the end of LHC Run 2, which began in 2015 and saw proton collisions take place at a centre-of-mass energy of 13 TeV. The total data accumulated since the start of Run 2 corresponds to an integrated luminosity of 160 fb^{-1} to both ATLAS and CMS. From 10 December, CERN's accelerator complex will enter "long shutdown 2" and undergo an extensive programme of renovation and upgrades, in particular for the High-Luminosity LHC. A week of LHC magnet training tests for operation at a future proton collision energy of 14 TeV is one of the first activities.

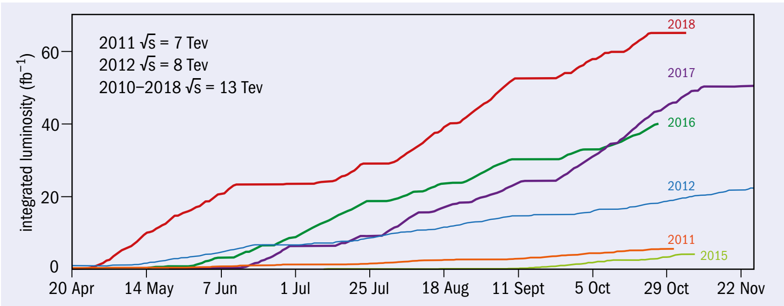
High performance

In terms of performance, LHC Run 2 has been a major success for both the machine and its detectors. In terms of physics output, highlights from ATLAS and CMS include several key measurements of the Higgs boson's properties, in particular its couplings to top and bottom quarks and to tau leptons, and numerous searches for physics beyond the Standard Model. LHCb has found a clutch of new hadrons, deepening our understanding of strong interactions, and has accumulated interesting results concerning the universality of lepton couplings. In the sphere of nuclear collisions, ALICE has dug even deeper into the extreme dynamics of the quark–gluon plasma – also finding strong evidence that this state is produced in proton–proton collisions.

This is just a flavour of the numerous results produced. So far, no firm signs of physics beyond the Standard Model have been seen at the LHC, but the majority of data collected during Run 2 are still to be analysed. Between now and the return of protons for Run 3 in 2021, the LHC experiment collaborations will throw everything they have at the data to see if anything new is lurking in the Run 2 data.

CERN-PHOTO-201802-030-6

The Large Hadron Collider photographed in 2018.



The high performance of the LHC during Run 2 (2015–2018) has taken the total integrated luminosity of proton–proton collisions in each of the high-luminosity experiments to around 190 fb^{-1}.

Sommaire en français

HADRON SPECTROSCOPY

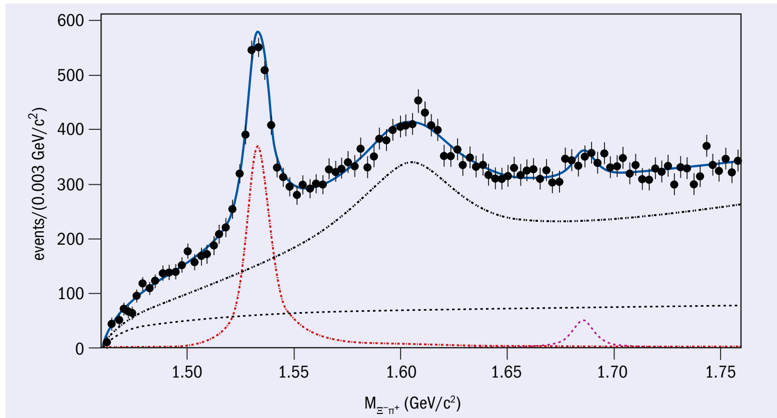
Doubly-strange baryon observed in Japan

High-luminosity collisions of electrons and positrons at the KEKB accelerator in Japan have established the existence of a new baryon with strangeness S = –2, shedding light on the structure of doubly-strange hyperon resonances. In a preprint submitted to *Physical Review Letters*, researchers at KEKB's Belle experiment report the first observation of the $\Xi(1620)^0$ based on a 980 fb^{-1} data sample. The collaboration also found evidence for the slightly heavier $\Xi(1690)^0$.

The constituent-quark model has been very successful in describing the Ξ or "cascade" baryon. Discovered in cosmic-ray experiments half a century ago, and corresponding to the ground state of the flavour-SU(3) octet, it contains one u or d quark plus two more massive quarks (the Ξ^0 is made of one u and two s quarks). However, some observed excited states do not agree well with the Standard Model prediction. The study of such unusual states therefore probes the limitation of the quark model and could reveal unexpected aspects of quantum chromodynamics (QCD).

Belle researchers uncovered the resonance from its decay to $\Xi^-\pi^+$ via $\Xi_c^+ \to \Xi^-\pi^+\pi^+$, measuring its mass and width to be 1610.4 ± 6.0 (stat) $^{+5.9}_{-3.5}$ (syst) MeV/c^2 and 59.9 ± 4.8 (stat) $^{+2.8}_{-3.0}$ (syst) MeV, respectively. The values are consistent with those from previous sightings at other experiments, and the width of the $\Xi(1620)^0$ turns out to be somewhat larger than that of the other exited Ξ states.

Experimental evidence for the $\Xi(1620) \to \Xi\pi$ decay was first reported in



The $\Xi^-\pi^+$ invariant mass spectrum, together with the fit result (blue), including: the $\Xi(1530)^0$ signal (red), $\Xi(1690)^0$ signal (pink), $\Xi(1620)^0$ signal and non-resonant contribution (dot-dashed black curve), and the combinatorial backgrounds (dotted black curve).

K^-p interactions in the 1970s, but there has been a lingering theoretical controversy about the interpretation of both the Ξ(1620) and Ξ(1690) states because the quark model predicts the first excited states of Ξ to have a mass of around 1800 MeV/c^2. The latest results from Belle hint that these states represent a new class of exotic hadrons, writes the team: "The situation is similar to the two poles of the Λ(1405) and suggests the possibility of two poles in the S = –2 sector. Studying these states may explain the riddle about the Λ(1405); consequently, the interplay between the S = –1 and S = –2 states can help resolve this long-standing problem of hadron physics."

The Belle detector has recently been superseded by Belle II at the upgraded SuperKEKB facility (*CERN Courier* September 2016 p32). Experiments at the LHC are also turning up new Ξ states. In 2012, CMS detected a Ξ_b^{*0}, while in 2014 the LHCb experiment discovered the $\Xi_b'^-$ and Ξ_b^{*-}, and, in 2017, the doubly charmed Ξ_{cc}^{++}. Taken together, hadron-spectroscopy studies such as these are helping to piece together the complex process by which fundamental QCD objects combine into hadronic matter (*CERN Courier* April 2017 p31).

Further reading

Belle Collaboration 2018 arXiv:1810.06181.

ACCELERATORS

Plasma lenses promise smaller accelerators

An international team has made an advance towards more compact particle accelerators, demonstrating that beams can be focused via a technique called active plasma lensing without reducing the beam quality.

Building smaller particle accelerators has been a goal of the particle accelerator community for decades, both for basic research and applications such as radiotherapy. In addition to new accelerating mechanisms, smaller accelerators require novel ways to focus particle beams.

Active plasma lensing uses a large electric current to set up strong magnetic fields in a plasma that can focus high-energy beams over distances of centimetres, rather than metres as is the case for conventional magnet-based techniques. However, the large current also heats the plasma, preferentially heating the centre of the lens. This temperature gradient leads to a nonlinear magnetic field, an aberration, which degrades the particle-beam quality.

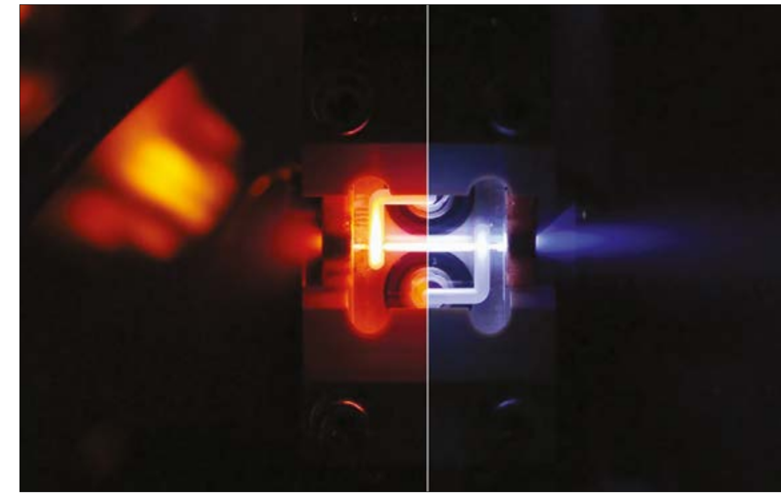
Using a high-quality 200 MeV electron beam at the CLEAR user facility at CERN (*CERN Courier* November 2017 p8), Carl A Lindstrøm of the University of Oslo, Norway, and collaborators recently made the first direct measurement of this aberration in an active plasma lens, finding it to be consistent with theory. More importantly, they discovered that this aberration can be suppressed by simply changing the gas used to make the plasma from a light gas (helium) to a heavier gas (argon). Changing the gas slows down the heat transfer so that the aberration does not have time to form, resulting in ideal, degradation-free focusing. It represents a significant step towards making active plasma lenses a standard accelerator component in the future, says the team.

CLEAR evolved from a test facility for the Compact Linear Collider (CLIC) called CTF3, which ended a successful programme in 2016. CLEAR offers general accelerator R&D and component studies for existing and possible future accelerator applications, such as high-gradient "X-band" acceleration methods (*CERN Courier* April 2018 p32), as well as prototyping and validation of accelerator components for the High-Luminosity LHC upgrade.

"Working at CLEAR was very efficient and fast-paced – not always the case in large-scale accelerator facilities," says Lindstrøm. "Naturally, we hope to continue our plasma lens research at CLEAR. One exciting direction is probing the limits of how strong these lenses can be. This is clearly the lens of the future."

Further reading

C A Lindstrøm *et al.* 2018 *Phys. Rev. Lett.* **121** 194801.



K Sjøbæk/CLEAR

An active plasma lens during discharge in both helium (left) and argon (right).

ANTIMATTER

Exploring how antimatter falls

Two new experiments at CERN, ALPHA-g and GBAR, have begun campaigns to check whether antimatter falls under gravity at the same rate as matter.

The gravitational behaviour of antimatter has never been directly probed, though indirect measurements have set limits on the deviation from standard gravity at the level of 10^{-6} (*CERN Courier* January/February 2017 p39). Detecting even a slight difference between the behaviour of antimatter and matter with respect to gravity would mean that Einstein's equivalence principle is not perfect and could have major implications for a quantum theory of gravity.

ALPHA-g, a close model of the ALPHA experiment, combines antiprotons from CERN's Antiproton Decelerator (AD) with positrons from a sodium-22 source and traps the resulting antihydrogen atoms in a vertical magnetic trap about 2 m tall. To measure their free-fall, the field is switched off so that the atoms fall under gravity and the position where the antiatoms annihilate with normal matter allows the rate to be determined precisely.

GBAR adopts a similar approach but takes antiprotons from the new and lower-energy ELENA ring attached to the AD (*CERN Courier* December 2016 p16) and combines them with positrons from a small linear accelerator to make antihydrogen ions. Once a laser has stripped all but one positron, the neutral antiatoms

CERN-PHOTO-201810-267-11

The insertion of the ALPHA-g experiment at the Antiproton Decelerator hall at CERN on 12 October.

will be released from the trap and allowed to fall from a height of 20 cm.

ALPHA-g began taking beam on 30 October, while ELENA has been delivering beam to GBAR since the summer, allowing the collaboration to perfect the beam-delivery system. Both experiments are being commissioned before CERN's accelerators are shut down on 10 December for a two-year period. The ALPHA-g team hopes to be able to gather enough data during this short period to make a first measurement of antihydrogen in free fall, while the brand new GBAR experiment aims to make a first measurement when antiprotons are back in the machine in 2021. A third experiment at the AD hall, AEgIS, which has been in operation for several years, is also measuring the effect of gravity on antihydrogen using yet another approach, based on a beam of antihydrogen atoms. AEgIS is also hoping to produce its first antihydrogen atoms this year.

So far, most efforts at the AD have focused on looking for charge–parity–time violation by studying the spectroscopy of antihydrogen and comparing it with that of hydrogen (*CERN Courier* March 2018 p30). This latest round of experiments opens a new avenue in antimatter exploration.

LHC EXPERIMENTS

CMS weighs in on flavour anomalies

Recent results from the LHCb and other experiments appear to challenge the assumption of lepton-flavour universality. To explore further, the CMS collaboration has recently conducted a new search probing one of the theories that attempts to explain these flavour "anomalies". Using 77.3 fb^{-1} of proton–proton collision data recorded in 2016 and 2017 at a centre-of-mass energy of 13 TeV, the CMS analysis is the first dedicated search for a neutral gauge boson with specific properties that couples only to leptons of the second and third family.

Although the Standard Model (SM) has been successful in describing current experimental results, it is generally believed to be incomplete. It cannot, for example, explain dark matter or the observed asymmetry between matter and antimatter in the universe. There are also several smaller differences between the experiment and the SM prediction that have been building up over the last few years. One set of intriguing anomalies has been reported by LHCb and other dedicated B-physics experiments, indicating a possible lepton-flavour universality violation in B-meson decays (*CERN Courier* April 2018 p23). Another is the long-standing tension in the measurement of the anomalous magnetic moment of the muon, for which an updated measurement is eagerly awaited (*CERN Courier* September 2018 p9).

One extension to the SM that has been proposed to explain these anomalies is an enlarged SM gauge group with an additional U(1) symmetry. Spontaneous breaking of this symmetry leads to the prediction of a new massive gauge boson, Z′. To keep the extended gauge symmetry free from quantum anomalies, only certain generation-dependent couplings are allowed. The model investigated by CMS promotes the difference in lepton numbers between the second and third generation to a local gauge symmetry, and until now has only been constrained slightly by experiment. Since the predicted Z′ boson only couples to second- and third-generation leptons, the only way to produce it at the LHC is as final-state radiation off one of these leptons. The ideal source of muons for the purposes of this search is the decay of the SM Z boson to two muons, which can be measured with excellent mass resolution (~1%) in CMS. If a Z′ boson exists, it will be radiated by one of the muons and decay subsequently to another pair of muons, leading to a final state with four muons.

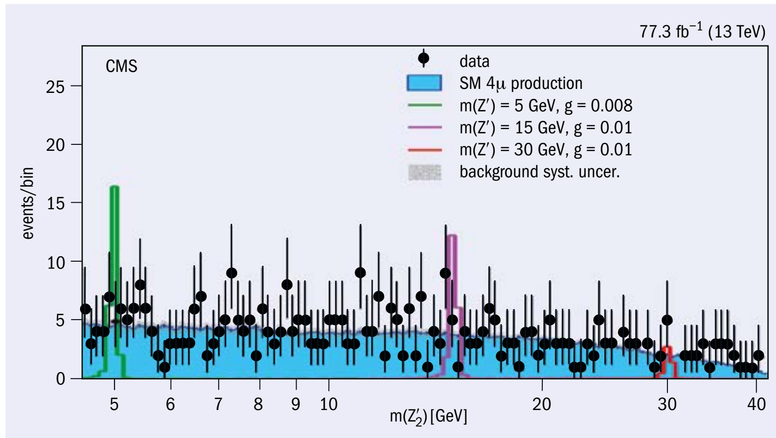


Fig. 1. The distribution of the opposite-sign muon pair with the lowest reconstructed invariant mass, $m(Z'_2)$, for data (points), SM background (solid histogram) and a few examples of a potential Z′ signal (open, superimposed histograms).

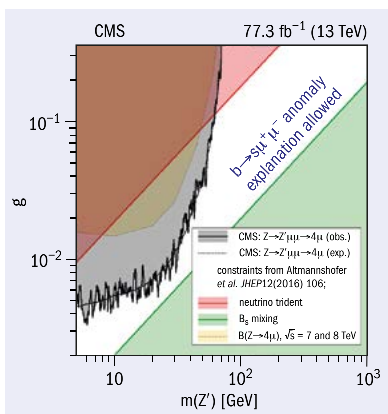


Fig. 2. The expected and observed limits at 95% confidence level on the gauge-coupling strength g as a function of the Z′ mass, and comparison with other experimental constraints. For comparison, the electroweak couplings g_{EW} and g'_{EW} are 0.6 and 0.3, respectively.

Such a final state is also produced by a rare SM Z-boson decay to four muons mediated by an off-shell photon. The first observation of this rare decay of the SM Z boson in proton–proton collisions was reported by CMS in 2012. In order to reduce this background, the search exploits the resonant character of the new gauge boson's di-muon decay. Events are selected that contain at least four muons with an invariant mass near the SM Z-boson mass. Di-muon candidates are then formed from muon pairs of opposite sign and a peak in their invariant mass distribution is sought, which would indicate the presence of a Z′ particle.

The event yields are found to be consistent with the SM predictions (figure 1). Upper limits of the order of 10^{-8}–10^{-7} are set on the branching fraction of a Z boson decaying to two muons and a Z′, with the latter also decaying into two muons, as a function of the Z′ mass. This can be interpreted as a limit on the Z′ particle's coupling strength to muons, and provides the first dedicated limits on these Z′ models at the LHC. Compared to other experiments and to indirect limits from the LHC obtained at lower centre-of-mass energies during Run 1, this search excludes a significant portion of parameter space favoured by the B-physics anomalies (figure 2). The analysis demonstrates the power and flexibility of the CMS experiment to adapt to and test new incoming physics models, which in turn react to previous experimental results, showing that experiments and theory go hand-in-hand.

Further reading

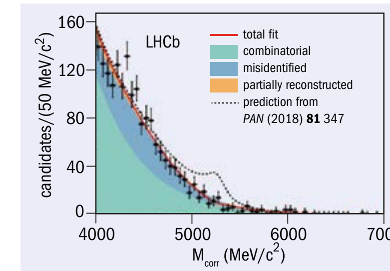
W Altmannshofer *et al.* 2016 *J. High Energy Phys.* **1612** 106.
CMS Collaboration 2018 arXiv:1808.03684.
CMS Collaboration 2012 *J. High Energy Phys.* **1212** 034.

LHCb constrains ultra-rare muonic B decay

Measurements of b-hadron decays with neutrinos in the final state are one of the best ways to understand how quarks decay, and in particular how they couple to leptons. With recent results from LHCb, BaBar and Belle raising questions about whether the Standard Model (with its assumption of lepton-flavour universality) is able to explain these couplings fully, further experimental results are needed.

However, studying these decays is notoriously tricky at a hadron collider, where the busy collision environment makes it challenging to control the background. Despite this, the LHCb collaboration has made unexpected progress in this area over the last few years, with a comparison of decays with taus and muons, and measurements the CKM element ratio $|V_{ub}/V_{cb}|$ that originally seemed impossible.

At first glance, measuring fully leptonic decays such as $B^+ \to \tau^+\nu_\tau$ and $B^+ \to \mu^+\nu_\mu$ seems a step too far, since there is only one charged particle as a signature and no reconstructed B-decay vertex. The key to accessing these processes is to allow additional particles to be radiated, while preserving the underlying decay amplitude. The decay $B^+ \to \mu^+\mu^-\mu^+\nu_\mu$ is a good example of this, where a hard photon is radiated and converts immediately into two additional muons. Such a signature is significantly more appealing experimentally: there is a vertex to reconstruct and the background is low, as there are not many B decays that produce three muons.



Mass spectrum for $B^+ \to \mu^+\mu^-\mu^+\nu_\mu$ candidates using the corrected mass technique. The shaded regions show estimated backgrounds. The dashed line shows what would be expected if the decay occurred at the higher rate predicted by a recent model.

B decays with a well-defined vertex and only one missing neutrino are becoming LHCb's "bread and butter" thanks to the so-called corrected mass technique. The idea behind the corrected mass is that if you are only missing one neutrino, then adding the momentum perpendicular to the B flight direction is enough to recover the B mass. This technique is only possible thanks to the precise vertex resolution provided by the LHCb's innermost detector, the VELO. Using this technique, LHCb expects to have a very good sensitivity for this decay, at a branching fraction level of 2.8×10^{-8} (equivalent to around one in 40 million B^+ decays) with the 2011–2016 data sample.

The LHCb collaboration searched for this decay using 5 fb^{-1} of data (see figure). The main backgrounds come from reconstructed muons that originate from different decays ("combinatorial") or from hadrons misidentified as muons ("misidentified"). No evidence for the signal is seen and an upper limit on the branching fraction of 1.6×10^{-8} is set at a confidence level of 95%.

The figure also shows a projected signal expected from a recent Standard Model prediction, which is based on the vector meson dominance model. This prediction includes two contributions to the decay: one in which two muons originate from a photon, and another in which they originate from the annihilation of a hadron (such as $\rho^0 \to \mu^+\mu^-$ or $\omega \to \mu^+\mu^-$). As can be seen, the data disfavour this prediction, which motivates further theoretical work to understand the discrepancy. The good sensitivity for this decay is encouraging, and raises interesting prospects for observing the signal with future datasets collected at the upgraded LHCb detector.

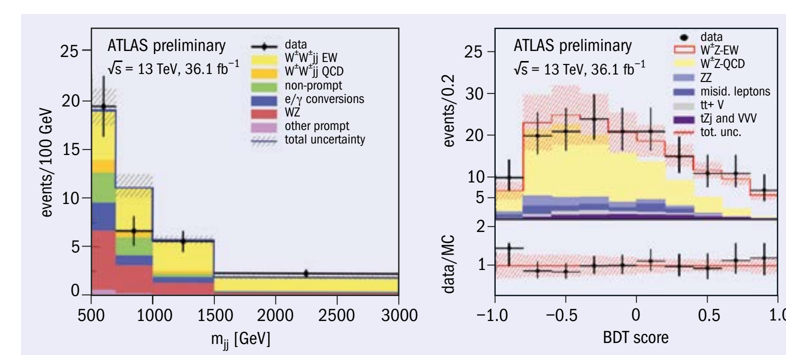
Further reading

LHCb Collaboration 2018 PAPER-2018-037.
A V Danilina and N V Nikitin 2018 *Phys. Atom. Nucl.* **81** 347.

ATLAS observes scattering of vector bosons

The exploration of W- and Z-boson interactions at the energy frontier probes the heart of the Brout–Englert–Higgs mechanism. The cross-section of longitudinal weak-boson scattering would diverge, resulting in meaningless values, were it not for the exact cancellation due to Higgs-boson contributions. The key processes for this exploration are the scattering between W and Z bosons emitted by quarks in proton–proton collisions, which are among the rarest processes of the Standard Model (SM) and that have remained inaccessible until very recently.

At the 2018 International Conference on High Energy Physics (ICHEP), held in Seoul on 4–11 July, ATLAS reported the observation of the $W^\pm W^\pm jj$ final state, and, for the first time, the observation of the $W^\pm Zjj$ final state produced by pure electroweak processes, among which vector-boson scattering (VBS) is dominant. Observation ▷



Left: the distribution of m_{jj} for selected $W^\pm W^\pm jj$ events. Right: the distribution of scores of the boosted decision tree for selected WZjj events, with the lower panel showing the ratio of data to the sum of signal and background contributions.

of the electroweak production of $W^{\pm}W^{\pm}jj$ was reported by the CMS collaboration in 2017.

ATLAS data corresponding to an integrated luminosity of 36 fb^{-1} collected in 2015 and 2016 at a centre-of-mass energy of 13 TeV were used. The two final states were searched for using W- and Z-boson decays to leptons (electrons or muons), featuring the typical signature of a centrally produced diboson system accompanied by two forward jets that are well separated in rapidity. The large invariant mass (m_{jj}) of the two jets was used to isolate signal events from the overwhelming background arising from strong interactions. Further selection requirements, utilising additional features in the two channels, were necessary to suppress this background.

In the WWjj channel, the strong-interaction contribution to the production can be greatly reduced by selecting events with the same W-boson charge. Remaining backgrounds arise from processes in which leptons are misidentified or the charge of the lepton is incorrectly measured. The analysis therefore focused on the reduction and control of these backgrounds that are estimated from data. Additional background from incompletely reconstructed WZ events was estimated from simulations. The final m_{jj} distribution of selected events is shown in the left-hand figure (p11), with the signal accumulating at large m_{jj} values. The analysis led to a significance of 6.9σ, qualifying for an observation.

Most of the background in the WZjj channel arises from strong-interaction processes contributing to the same final state. Kinematic variables that show distinct differences between electroweak and strong production were exploited to isolate the signal using a multivariate discriminant from a boosted decision tree (figure, right). The analysis leads to an observed significance of 5.6σ.

These observations open up a new era of exploration of a yet largely unknown part of the SM: the quartic couplings of weak bosons. The larger amounts of data collected during LHC Run 2 and future runs will allow for a detailed characterisation of VBS interactions using differential cross-section measurements. Such measurements combined with refined theory modelling provide sensitive tests of the electroweak sector of the SM, and may reveal signs of new physics.

Further reading

ATLAS Collaboration 2018 ATLAS-CONF-2018-030.
ATLAS Collaboration 2018 ATLAS-CONF-2018-033.

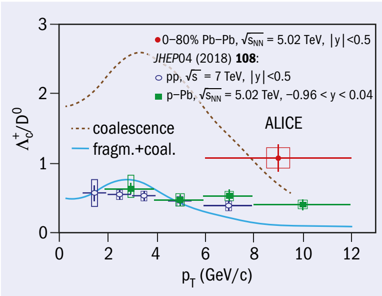
Λ_c^+-baryon probes charm-quark hadronisation

ALICE

The first measurement of Λ_c^+-baryon production in lead–lead (Pb–Pb) collisions at an energy of 5.02 TeV per colliding nucleon pair was presented by the ALICE collaboration at the International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions, held at Aix-Les-Bains from 30 September to 5 October. This measurement is essential to understand how charm-quark hadronisation is affected by the presence of the quark–gluon plasma (QGP) created in high-energy heavy-ion collisions.

Charm quarks are produced early in the collision, interact with the plasma as they propagate through it, and eventually hadronise. It has been suggested that the presence of many quarks in the final state of a heavy-ion collision may affect the hadronisation process: charm quarks could form hadrons by recombining with light quarks that happen to be nearby. In high-energy proton–proton (pp) collisions, the main hadronisation mechanism is through the formation of light quarks in a parton shower, known as “fragmentation”.

$\Lambda_c^+ \to pK_s^0$ decays, and their charge conjugates, were reconstructed by ALICE in Pb–Pb collisions at mid-rapidity ($|y| < 0.5$) in the transverse momentum interval $6 < p_T < 12$ GeV/c and within 0–80% centrality range. The ratio of the production yields of Λ_c^+ baryons (which consist of a charm quark and two light quarks) and D^0 mesons (which contain a charm quark and a single, light antiquark)



The Λ_c^+/D^0 baryon-to-meson ratio as a function of p_T in the 0–80% most central Pb–Pb collisions, compared with the measurements in pp and p–Pb collisions and predictions from models (S Plumari et al. *2018 Eur. Phys. J.* **4** *348).*

was measured. The Λ_c^+/D^0 ratio in Pb–Pb collisions is larger than those measured in minimum-bias pp collisions at 7 TeV and in p–Pb collisions at 5.02 TeV. The difference between the results in Pb–Pb and p–Pb collisions is about two times the standard deviation of the combined statistical and systematic uncertainties. The measured ratio in Pb–Pb collisions is also compatible with the Λ_c^+/D^0 ratio measured in gold–gold collisions at the Relativistic Heavy-Ion Collider at Brookhaven in the US. The measurement was compared with model calculations including different implementations of charm-quark hadronisation. The calculation with a pure coalescence scenario describes the experimental result, while adding a fragmentation contribution leads to a ratio that is smaller than that observed.

For this first measurement of Λ_c^+-baryon production in Pb–Pb collisions, the uncertainties are still large and it is therefore not possible to draw a firm conclusion about the relative importance of recombination and fragmentation for charm-quark hadronisation. Moreover, it remains crucial to understand the charm-baryon production mechanisms in pp and p–Pb collisions, in particular, whether the assumptions made on the basis of e^+e^- results also hold for fragmentation in hadronic collisions (*CERN Courier* March 2018 p12). The baryon-to-meson ratio has now been studied with light-flavour, strange and charm hadrons. All baryon-to-meson ratios in pp and p–Pb collisions show a characteristic p_T dependence with an enhancement at intermediate p_T values up to around 4 GeV/c, which still needs further investigation.

Future datasets, to be collected during the heavy-ion run in 2018 and during LHC Run 3 and 4 after a major upgrade of the ALICE detector, will improve the Λ_c^+-baryon production measurement. With a higher precision and a finer granularity in p_T and centrality, these measurements are fundamental in determining the role of recombination for charm-quark hadronisation.

Further reading

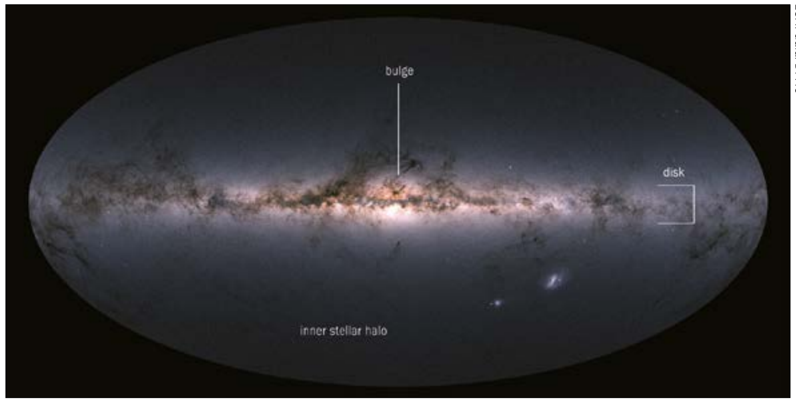
ALICE Collaboration 2018 arXiv:1809.10922.

COMPILED BY MERLIN KOLE, DEPARTMENT OF PARTICLE PHYSICS, UNIVERSITY OF GENEVA

Gaia finds evidence of old Milky Way merger

Many of the stars appearing in the night sky did not originate from within our galaxy, concludes a new study of data from the European Space Agency's Gaia observatory. Instead, Gaia has found evidence that these stars formed in a smaller galaxy that merged with ours about 10 billion years ago.

Gaia was launched in 2013 with the aim of measuring the positions and distances of more than one billion astronomical objects (mainly stars) in and around our galaxy with unprecedented precision. Using Gaia data containing about seven million stars, Amina Helmi of the University of Groningen in the Netherlands and colleagues have found that a subset of these stars is different from the bulk of the stars in the Milky Way. Earlier research had shown that some stars in the galaxy's inner stellar halo, which surrounds the central bulge and disk, have different chemical abundances from the bulge and disk stars (see figure). But the latest study found that these halo stars also exhibit orbits around the galactic centre that differ significantly from the rest of the stars.



ESA/Gaia/DPAC

Gaia's all-sky view of the Milky Way and neighbouring galaxies, based on measurements of nearly 1.7 billion stars. A recent analysis of Gaia data shows that stars from the galaxy's inner stellar halo, which surrounds the central bulge and disk, formed in a smaller galaxy that merged with the Milky Way in the past.

The orbits of the stars in a galaxy typically follow that of the gas cloud in which they were born, which means that a proto-galaxy consisting of an orbiting gas cloud will produce stars orbiting along with the cloud. However, Helmi and co-workers show that many of the Milky Way's halo stars orbit backwards relative to the rest of the galaxy, suggesting that their origin is probably different. The team then compared the Gaia observations with simulations in which the Milky Way merged in the past with a smaller galaxy with 25% of its mass, finding a remarkable similarity between the observed and simulated orbits.

Additional analysis of spectral data from APOGEE-2 (Apache Point Observatory Galactic Evolution Experiment), which is part of the Sloan Digital Sky Survey, revealed that the halo stars contain fewer of the chemical elements that are produced in specific types of supernovae, indicating that they are significantly older than the bulk of the Milky Way's stars.

Taken together, the results suggest that, after the smaller galaxy (named Gaia–Enceladus by the authors) merged with the Milky Way, it lost all the gas it needed to produce new stars. As a result, only the old stars survived and no new stars were born. The age of the youngest stars from Gaia–Enceladus – about 10 billion years – can therefore tell astronomers when the merger took place. A final piece of evidence that this dramatic event occurred comes from Gaia data of 13 star clusters orbiting the Milky Way at large distances. The orbits of these clusters, which contain millions of gravitationally bound stars, match those that would be expected for the remnants of Gaia–Enceladus.

The results, published in *Nature*, constitute one of the first major discoveries to emerge from Gaia data. They shed light on the origin of our galaxy and galaxy mergers in general, but much more will no doubt be learned from the vast amount of data that the satellite has gathered.

Further reading

A Helmi *et al.* 2018 *Nature* **563** 85.

Picture of the month

This single image captures three objects with very different lifetimes. The bright yellow line is the result of a meteor that disintegrated in Earth's atmosphere and was visible for less than a second (*CERN Courier* October 2018 p19). The meteor was probably a piece of debris from comet 21P/Giacobini–Zinner. This comet is also captured in the centre of the image (white streak of light) and is responsible for the yearly Draconid meteor shower. The comet and its long dust tail have been visible across the night sky for several months but are now slowly fading as the comet moves away from Earth. The image is completed by the Seagull Nebula (pink), which consists of gas illuminated by surrounding stars (*CERN Courier* May 2018 p17) and will probably remain visible for many thousands of years.

T Sambommatsu

Meet the Extremely Brilliant Source

On its 30th anniversary, the European Synchrotron Radiation Facility is dismantling its flagship storage ring to make way for a revolutionary X-ray source.

ESRF

A mock-up of the new storage ring with an X-ray beamline branching off to the right.

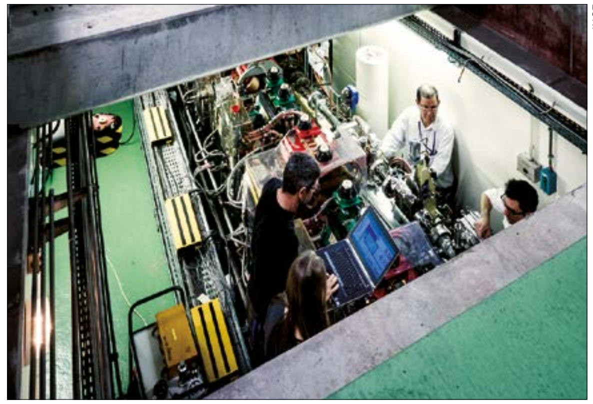
If there is one area where particle accelerators have had the most significant scientific impact, it is surely X-ray science. Each year, tens of thousands of experiments are carried out at the 50 or so synchrotron X-ray facilities worldwide, spanning a wide range of disciplines – from materials science and archaeology, through structural biology, planetary science, environmental science, nanotechnology and more.

Nestled between two rivers in northwest Grenoble, France, the 22 partner-nation European Synchrotron Radiation Facility (ESRF) is one of the world's leading light sources. It is based on a 844 m-circumference 6 GeV electron storage ring with 44 specialised experimental stations serving around 5000 users per year, and so far experiments there have contributed to over 32,000 peer-reviewed publications. Established in 1988 and inaugurated in 1994, the ESRF was the first third-generation synchrotron, using periodic magnetic arrays called undulators to deliver the world's brightest X-ray beams. Since then, numerous national light sources have sprung up, alongside flagship third-generation facilities in Japan and the US.

A decade ago, the ESRF embarked on a €330 million upgrade programme to help ensure Europe's leading position in the light-source world. At its core is a first-of-its-kind storage ring with an increased X-ray brightness and coherent flux 100 times higher than before, in addition to new X-ray beamlines, instrumentation, computing and other improvements. The ESRF upgrade will allow users to probe complex materials at the atomic level in greater detail, with higher quality, and much faster. The final beam of the current ESRF storage ring will be extracted on 10 December, and operations will cease for 20 months while the new machine – called the Extremely Brilliant Source (EBS) – takes shape.

Synchrotron radiation, which spans a broad spectrum up to the hard X-ray region, is famously something particle physicists try to avoid, as it limits the energy of circular colliders. But the power of X rays to elucidate the structure of matter had been known since the early 1900s, and it wasn't long before this by-product of particle physics was put to use. Following the rise of storage rings during the 1960s, nascent synchrotron X-ray users carried out experiments "parasitically" by placing their apparatus in the path of synchrotron radiation from circular particle colliders. By the 1970s, dedicated second-generation sources started to be built, but it was not until the 1990s that third-generation light sources such as the ESRF were possible. Instead of just producing X-rays from the curved trajectories of electrons passing through a dipole, these facilities use long zip-like arrays of alternating-polarity magnets called undulators to produce much brighter, more spectrally coherent, X-ray beams. This allows users to probe matter at shorter spatial and temporal scales.

Inspecting a girder carrying elements of a single EBS cell.



The existing storage ring in place at the ESRF.

Key to increased X-ray brightness at a synchrotron is a parameter called the beam emittance, which is a measure of the size and spread of the electron beam as it circulates. Third-generation storage rings reduce the vertical emittance to the X-ray diffraction limit, thanks to a lattice design that decouples the vertical and horizontal motions of the electrons. Reducing the horizontal component is more challenging. One approach is to build a bigger storage ring (the 6.3 km tunnel at Fermilab that housed the Tevatron collider has been mooted as a possible site for an ultimate X-ray source, for example). However, that option isn't always suitable, and the ESRF had to find a smarter solution.

The existing ESRF storage ring consists of 32 cells each 27 m long and made up of sequences of magnets, vacuum chambers and position monitors. Technically it's called a double bend achromat lattice, since it relies on two dipoles per cell and because electrons of different energies are bent and focused in the same way (achromatically) resulting in very collimated and stable beams.

The new EBS lattice has the same footprint as the previous machine and will leave the present beamline layout unchanged. It is based on a hybrid multi-bend achromat (HMBA) with seven, as opposed to two, bending magnets per cell and optics that maximise the stable phase space volume available for the electron beam, reducing the horizontal emittance. The result is a tighter packing of electrons, increasing the brightness and degree of coherence of the X-rays by two orders of magnitude. This gives the EBS beams laser-like properties approaching those of X-ray free-electron lasers (XFELs) such as the European XFEL (*CERN Courier* July/August 2017 p18), and will make EBS the first high-energy fourth-generation synchrotron light source.

Inspired by SuperB

The EBS lattice uses concepts developed for the former SuperB project (an asymmetric electron—positron collider for flavour-physics studies) which, unusually for a collider, had an optimal horizontal emittance close to zero. The physicist behind the design, Pantaelo Raimondi, who led the SuperB project at INFN Frascati (and who is also the originator of the crab-waist technique to maximise collider luminosity, which is currently being considered for almost all future high-energy colliders) became director of accelerators at the ESRF in 2012 and set about the task of building a new kind of light source. An important moment in the evolution of the HMBA came at a workshop at CERN in 2011, when Raimondi realised the synergy with the multi-bend achromat design for an advanced synchrotron in Lund, Sweden, called MAX IV (*CERN Courier* September 2016 p39).

The challenges facing the ESRF's accelerator physicists, engineers and technicians are huge. The new storage ring requires 1000 innovative magnets – nearly twice as many as in the previous ring. These have to be squeezed into the same space inside the accelerator tunnel, so each of them has to be more compact and generate magnetic fields up to three times stronger than existing models. The vacuum chambers also have had to be redesigned to fit the limited space in and around the magnets, while the mechanical tolerances of some components have shrunk to within a hundredth of a millimetre. Non-evaporable getter (NEG) technologies pioneered at CERN are to play an important role in overcoming these challenges. EBS will use permanent-magnet technology for its 128 dipoles, and around 90% of the existing ESRF infrastructure will also be reused. The reduced beam energy loss due to unwanted synchrotron radiation and the optimised magnet design have also resulted in a decrease of the power consumption of the synchrotron by about 30%.

Last year, engineers built an entire EBS cell, consisting of girders, magnets, vacuum chambers and other components. This allowed the team to confirm the engineering principles of the new arc and to start series production of the storage-ring components. The existing storage ring will be dismounted by April 2019 and EBS will be installed later in the year and commissioned by March 2020, with user service resuming by September that year.

The EBS uses concepts developed for the SuperB electron–positron collider for flavour physics.

Four brand new beamlines will be designed to take full advantage of the EBS, while others will be refurbished, and the project has a special development programme to address the optics that transform the raw X-ray beam into a form suited for experiments. The X-ray detectors themselves are also being developed to handle the increased flux, with one technology based on the MEDIPIX3RX chip developed by the Medipix3 collaboration, of which the ESRF and CERN are partners. Control systems, mechatronics and software are other key areas of work to ensure the EBS is ready when it enters user mode two years from now.

Lattice travels

The EBS lattice has inspired other major light sources around the world. In addition to MAX IV, which was inaugurated in 2016, several multi-bend achromat synchrotrons are under planning or construction. This includes Sirius in Brazil but also upgrades at high-energy synchrotrons such as the Advanced Photon Source (APS) at Argonne National Laboratory in the US. Meanwhile, the Advanced Light Source (ALS) in California is moving towards a conceptual design report, and SPring-8 in Japan is pursuing a HMBA that will enter operation on a similar timescale. The long-term goal is to one day build an "ultimate" storage ring in which the horizontal emittance reaches the fundamental X-ray diffraction limit, as is the case today for the vertical emittance. Meanwhile, XFELs are starting to so sprout up in the way storage rings did around the turn of the millennium.

Particle physics will continue to play a vital role in X-ray science by driving accelerators forward and sharing vacuum, detector and other technologies. In fact, when workers come to dismantle and rebuild the ESRF storage ring in the coming weeks and months, they will also be ripping out and remounting parts of the radio-frequency (RF) system of CERN's Large Electron–Positron (LEP) collider, the forerunner to the LHC. LEP's RF system was the starting point of the ESRF design and teams at both laboratories, located just 150 km apart, collaborated closely to turn third-generation light sources from an idea into reality.

Résumé

À la rencontre d'une source extrêmement brillante

Pour son 30e anniversaire, le 10 décembre, l'Installation européenne de rayonnement synchrotron de Grenoble (France) commencera le démantèlement de son anneau de stockage phare afin de laisser la place à une installation de rayons X révolutionnaire, appelée la Source de lumière extrêmement brillante (EBS). Cet anneau de stockage, le premier de ce type, produira des rayons X plus brillants et un flux cohérent 100 fois plus élevé que l'installation précédente, ce qui permettra à ses utilisateurs de sonder des matériaux complexes au niveau atomique de façon plus détaillée, avec une meilleure qualité et beaucoup plus rapidement.

Matthew Chalmers, CERN.

The deepest clean lab in the world

The great depth and cleanliness of SNOLAB allows the study of extremely rare interactions and weak processes.

Deep in a mine in Greater Sudbury, Ontario, Canada, you will find the deepest flush toilets in the world. Four of them, actually, ensuring the comfort of the staff and users of SNOLAB, an underground clean lab with very low levels of background radiation that specialises in neutrino and dark-matter physics.

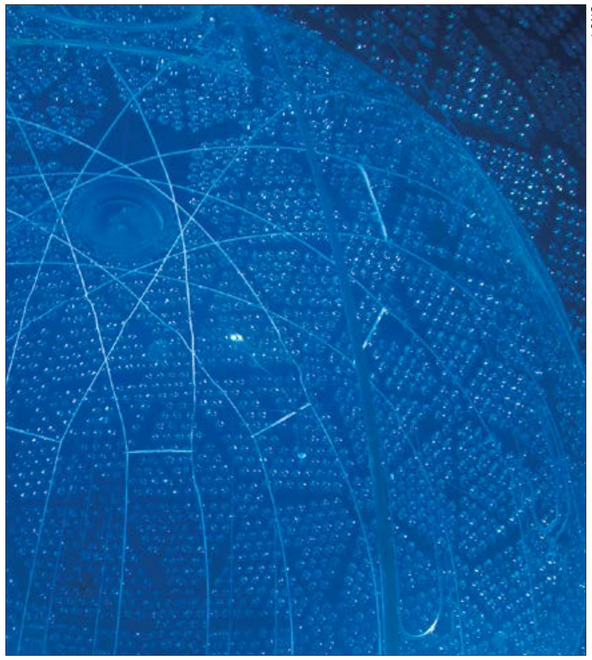
Toilets might not be the first thing that comes to mind when discussing a particle-physics laboratory, but they are one of numerous logistical considerations when hosting 60 people per day at a depth of 2 km for 10 hours at a time. SNOLAB is the world's deepest cleanroom facility, a class-2000 cleanroom (see panel overleaf) the size of a shopping mall situated in the operational Vale Creighton nickel mine. It is an expansion of the facility that hosted the Sudbury Neutrino Observatory (SNO), a large, heavy-water detector designed to detect neutrinos from the Sun. In 2001, SNO contributed to the discovery of neutrino oscillations, leading to the joint award of the 2015 Nobel Prize in Physics to SNO spokesperson Arthur B McDonald and Super-Kamiokande spokesperson Takaaki Kajita.

Initially, there were no plans to maintain the infrastructure beyond the timeline of SNO, which was just one experiment and not a designated research facility. However, following the success of the SNO experiment, there was increased interest in low-background detectors for neutrino and dark-matter studies.

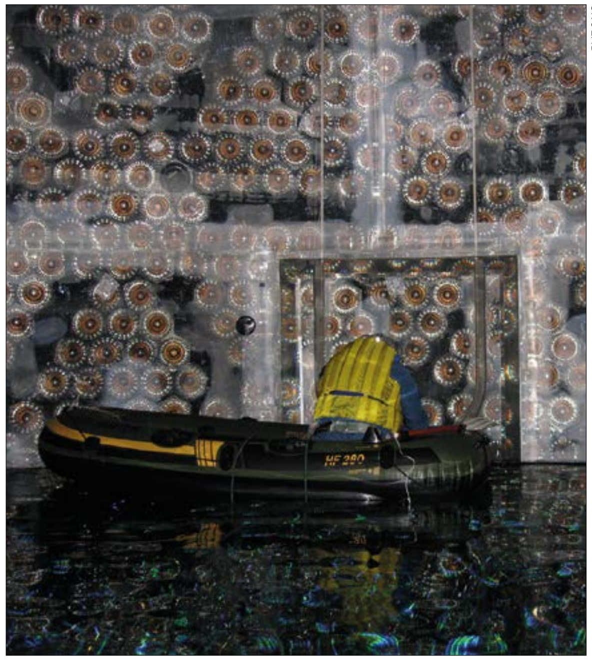
Building on SNO's success

The SNO collaboration was first formed in 1984, with the goal of solving the solar neutrino problem. This problem surfaced during the 1960s, when the Homestake experiment in the Homestake Mine at Lead, South Dakota, began looking for neutrinos created in the early stages of solar fusion. This experiment and its successors, using different target materials and technologies, consistently observed only 30–50% of the neutrinos predicted by the standard solar model. A seemingly small nuisance posed a large

A view of the SNOLAB underground laboratory. (Image credit: SNOLAB)



SNO+



SNOLAB

The SNO+ neutrino detector (left). A researcher inspects the acrylic walls inside the SNO+ detector (right).

problem, which required a large-scale solution.

SNO used a 12 m-diameter spherical vessel containing 1000 tonnes of heavy water to count solar neutrino interactions. Canada had vast reserves of heavy water for use in its nuclear reactors, making it an ideal location for such a detector. The experiment also required an extreme level of cleanliness, so that the signals physicists were searching for would not be confused with background events coming from dust, for instance. The SNO collaboration also had to develop new techniques to measure the inherent radioactivity of their detector materials and the heavy water itself.

Using heavy water gave SNO the ability to observe three different neutrino reactions: one reaction could only happen with electron neutrinos; one was sensitive to all neutrino flavours (electron, muon and tau); and the third provided the directionality pointing back to the Sun. These three complementary interactions let the team test the hypothesis that solar neutrinos were changing flavour as they travelled to Earth. In contrast to previous experiments, this approach allowed SNO to make a measurement of the parameters describing neutrino oscillations that didn't depend on solar models. SNO's data confirmed what previous experiments had seen and also verified the predictions of theories, implying that neutrinos do indeed oscillate during their Sun–Earth journey. The experiment ran for seven years and produced 178 papers accumulating more than 275 authors.

In 2002, the Canadian community secured funding to create an extended underground laboratory with SNO as the starting point. Construction of SNOLAB's underground facility was completed in 2009 and two years later the last experimental hall entered "cleanroom" operation. Some 30 letters of interest were received from different collaborations proposing potential experiments, helping to define the requirements of the new lab.

SNOLAB's construction was made possible by capital funds totalling CAD$73 million, with more than half coming from the Canada Foundation for Innovation through the International Joint Venture programme. Instead of a single giant cavern, local company Redpath Mining excavated several small and two large halls to hold experiments. The smaller halls helped the engineers manage the enormous stress placed on the rock in larger underground cavities. Bolts 10 m long stabilise the rock in the ceilings of the remaining large caverns, and throughout the lab the rock is covered with a 10 cm-thick layer of spray-on concrete for further stability, with an additional hand-troweled layer to help keep the walls dust-free. This latter task was carried out by Béton Projeté MAH, the same company that finished the bobsled track in the 2010 Vancouver Winter Olympics.

In addition to the experimental halls, SNOLAB is equipped with a chemistry laboratory, a machine shop, storage areas, and a lunchroom. Since the SNO experiment was still running when new tunnels and caverns were excavated, the connection between the new space and the original clean lab area was completed late in the project. The dark-matter experiments DEAP-1 and PICASSO were also already running in the SNO areas before construction of SNOLAB was completed.

Dark matter, neutrinos, and more

Today, SNOLAB employs a staff of over 100 people, working on engineering design, construction, installation, technical support and operations. In addition to providing expert and local support to the experiments, SNOLAB research scientists undertake research

Subterranean physics in an ultraclean environment

Underground laboratories such as SNOLAB house experiments searching for very rare events, which are typically produced by weak interactions. One of the challenges in achieving greater sensitivities is background radiation.

There are many radiation sources that can interfere with the experiments: radioactive isotopes in the environment, shielding and detector materials, as well as particles created by cosmic rays including muons, neutrons, and other hadrons from high-energy interactions in Earth's atmosphere. SNOLAB's depth protects the lab from cosmic rays as they are filtered out by the rock above. Additionally, the whole laboratory is a cleanroom, with fewer than 2000 particulates with a diameter larger than 0.5 μm per cubic foot of air. For comparison, the ambient air outside in a typical city environment contains 1,000,000 particulates per cubic foot, while the level in the mine environment outside SNOLAB is even higher.

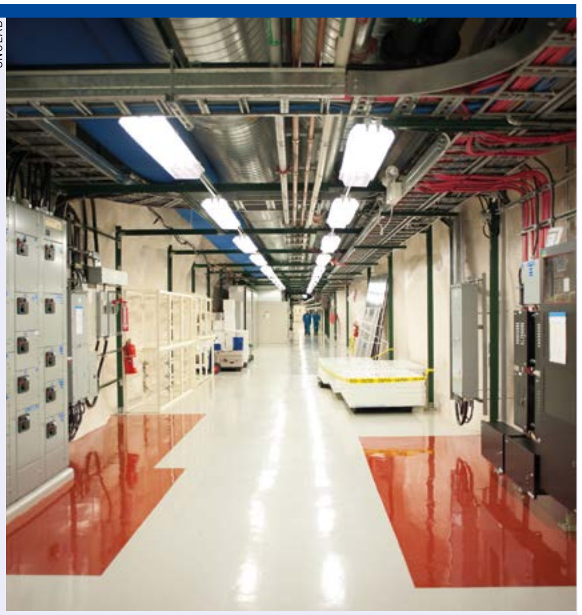
Significant controls are in place to prevent mine dust from entering the lab, since the rock contains isotopes of uranium and thorium. Everything entering SNOLAB, from equipment to experimental components to supplies, is cleaned to maintain the contamination-free environment. Items like lunch are protected from the mine dust with a double-bag system: one is removed on the "dirty" side of the facility, and one upon entering the clean side where the lab facilities are. Everything else is washed thoroughly in the "carwash" – each nut, bolt, and water bottle, as well as bigger items.

People are no exception. After a 1.5 km walk through the mine tunnels, and prior to entering the facility, staff and users of the lab wash their boots and leave them, along with mine gear, at the entrance. They then take a shower and put a clean set of garments, including socks, a shirt, and coveralls designed to trap contaminants that are naturally generated by skin and the body. Hairnets are also worn, and all the clothes and towels worn and used in the laboratory are washed underground.

Steps are also taken to reduce the particulate rate inside the lab and to control other environmental parameters such as temperature, humidity and pressure. All the air delivered to SNOLAB passes through high-efficiency particulate filters, while sticky mats designed to trap dust and residual dirt are placed on the floor at passage junctions and doors. Laser dust-monitors also track the particulate rate in the lab's experimental halls.

Some 200,000 showers are estimated to have been taken by SNOLAB workers so far. In addition, to enter certain lab areas such as the SNO+ deck, an air shower is mandatory to further reduce possible dust deposition. Maintaining a class-2000 clean lab underground is challenging but necessary for SNOLAB's world-class science programme.

SNOLAB



SNOLAB is a class-2000 cleanroom. Everything entering the laboratory is cleaned to maintain the contamination-free environment.

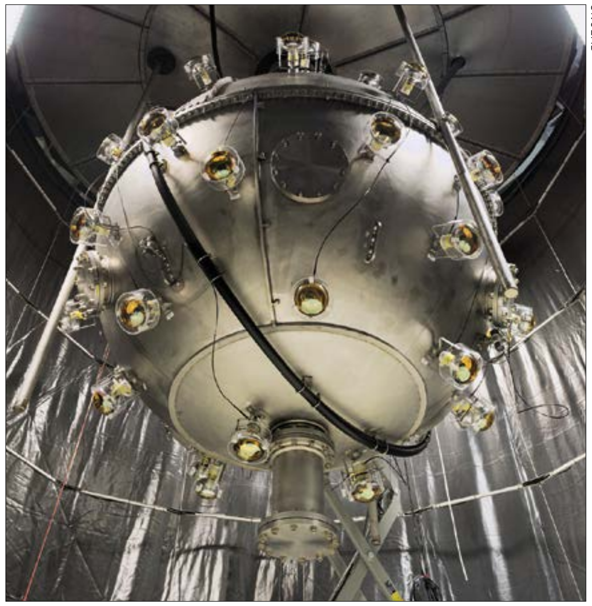
in their own right as members of the collaborations.

With so much additional space, SNOLAB's physics programme has expanded greatly during the past seven years. SNO has evolved into SNO+, in which a liquid scintillator replaces the heavy water to increase the detector's sensitivity. The scintillator will be doped with tellurium, making SNO+ sensitive to the hypothetical process of neutrinoless double-beta decay. Two of tellurium's natural isotopes (^{128}Te and ^{130}Te) are known to undergo conventional double-beta decay, making them good candidates to search for the long-sought neutrinoless version. Detecting this decay would violate lepton-number conservation, proving that the neutrino is its own antiparticle (a Majorana particle). SNO+ is one of several experiments currently hunting this process down.

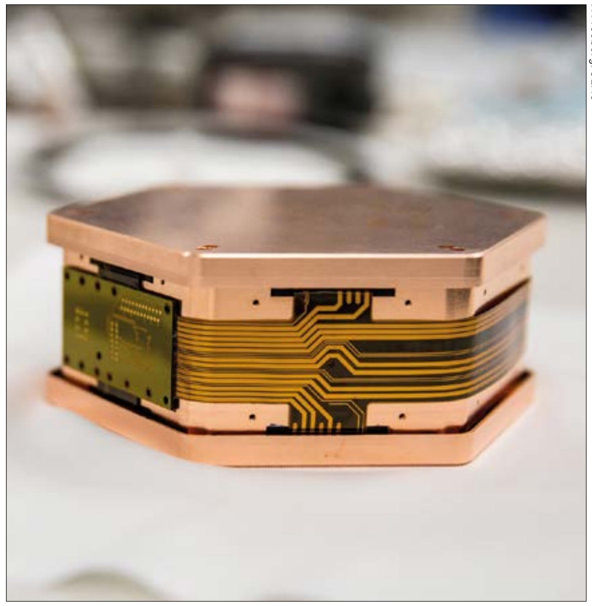
Another active SNOLAB experiment is the Helium and Lead Observatory (HALO), which uses 76 tons of lead blocks instrumented with 128 helium-3 neutron detectors to capture the intense neutrino flux generated when the core of a star collapses at the early stages of a supernova. Together with similar detectors around the world, HALO is part of a supernova early-warning system, which allows astronomers to orient their instruments to observe the phenomenon before it is visible in the sky.

With no fewer than six active projects, dark-matter searches comprise a large fraction of SNOLAB's physics programme. Many different technologies are employed to search for the dark-matter candidate of choice: the weakly interacting massive particle (WIMP). The PICASSO and COUPP collaborations were both using bubble chambers to search for WIMPS, and merged into the very successful PICO project. Through successive improvements, PICO has endeavoured to enhance the sensitivity to WIMP spin-dependent interactions by an order of magnitude every couple of years. Its sensitivity is best for WIMP masses around 20 GeV/c^2. Currently the PICO collaboration is developing a much larger version with up to 500 litres of active-mass material.

DEAP-3600, successor to DEAP-1, is one of the biggest dark-matter detectors ever built, and it has been taking data for almost two years now. It seeks to detect spin-independent interactions between WIMPs and 3300 kg of liquid argon contained in a 1.7 m-diameter acrylic vessel. The best sensitivity will be achieved for a WIMP mass of 100 GeV/c^2. Using a different technology, the DAMIC (Dark Matter In CCDs) experiment employs CCD



SNOLAB



A Freeberg/SLAC

With 3300 kg of liquid argon contained in an acrylic vessel, the DEAP-3600 detector at SNOLAB (left) is one of the biggest dark-matter detectors ever made. Right: the SuperCDMS SNOLAB germanium crystal detector within its protective copper housing and electrical readout cable wrapped around the exterior.

sensors, which have low intrinsic noise levels, and is sensitive to WIMP masses as low as 1 GeV/c^2.

Although the science at SNOLAB primarily focuses on neutrinos and dark matter, the low-background underground environment is also useful for biology experiments. REPAIR explores how low radiation levels affect cell development and repair from DNA damage. One hypothesis is that removing background radiation may be detrimental to living systems. REPAIR can help determine whether this hypothesis is correct and characterise any negative impacts. Another experiment, FLAME, studies the effect of prolonged time spent underground on living organisms using fruit flies as a model. The findings from this research could be used by mining companies to support a healthier workforce.

Future research

There are many exciting new experiments under construction at SNOLAB, including several dark-matter experiments. While the PICO experiment is increasing its detector mass, other experiments are using several different technologies to cover a wide range of possible WIMP masses. The SuperCDMS experiment and CUTE test facility use solid-state silicon and germanium detectors kept at temperatures near absolute zero to search for dark matter, while the NEWS-G experiment will use gasses such as hydrogen, helium and neon in a 1.4 m-diameter copper sphere.

SNOLAB still has space available for additional experiments requiring a deep underground cleanroom environment. The Cryopit, the largest remaining cavern, will be used for a next-generation double-beta-decay experiment. Additional spaces outside the large experimental halls can host several small-scale experiments. While the results of today's experiments will influence future detectors and detector technologies, the astroparticle physics community will continue to demand clean underground facilities to host the world's most sensitive detectors. From an underground cavern carved out to host a novel neutrino detector to the deepest cleanroom facility in the world, SNOLAB will continue to seek out and host world-class physics experiments to unravel some of the universe's deepest mysteries.

Further reading

A B McDonald *et al* 2003 *Scientific American* **288** 40.
F Duncan *et al* 2010 *Ann. Rev. Nucl. Part. Sci.* **60** 163.

Résumé

La salle blanche la plus profonde du monde

L'installation SNOLAB, située dans la mine de nickel de Creighton (Canada) exploitée par Vale, est la salle blanche la plus profonde du monde. Il s'agit d'une extension de l'installation qui a accueilli l'Observatoire de neutrinos de Sudbury (SNO), lequel a contribué à la découverte des oscillations des neutrinos. Initialement, il n'était pas prévu que cette infrastructure serait conservée après la fin du programme du SNO, mais son succès a renforcé l'intérêt pour l'utilisation de détecteurs à bruit de fond faible pour les études sur les neutrinos et la matière noire. Aujourd'hui, SNOLAB a un riche programme expérimental consacré à l'étude des interactions extrêmement rares et des processus liés à la force faible.

Erica Caden, **Pierre Gorel**, **Ian Lawson** and **Silvia Scorza**, SNOLAB.

CERN-PHOTO-7902525-1

The tale of a billion-trillion protons

Linac2, the machine that feeds CERN's accelerator complex with protons, has entered a well-deserved retirement after 40 years of service.

Before being smashed into matter at high energies to study nature's basic laws, protons at CERN begin their journey rather uneventfully, in a bottle of hydrogen gas. The protons are separated by injecting the gas into the cylinder of an ion source and making an electrical discharge, after which they enter what has become the workhorse of CERN's proton production for the past 40 years: a 36 m-long linear accelerator called Linac2. Here, the protons are accelerated to an energy of 50 MeV, reaching approximately one-third of the speed of light, ready to be injected into the first of CERN's circular machines: the Proton Synchrotron Booster (PSB), followed by the Proton Synchrotron (PS) and the Super Proton Synchrotron (SPS). At each stage of the chain, they may end up driving fixed-target experiments, generating exotic beams in the ISOLDE facility, or being injected into the Large Hadron Collider (LHC) to be accelerated to the highest energies.

Situated at ground level on the main CERN site, Linac2 has delivered all of the protons for the CERN accelerator complex since 1978. Construction of Linac2 started in December 1973, and the first 50 MeV beam was obtained on 6 September 1978. Within a month, the design current of 150 mA was reached and the first injection tests in the PSB started. Routine operation of the PSB started soon afterwards, in December 1978. As proudly announced by CERN at the time, Linac2 was completed on budget and on schedule, for an overall cost of 23 million Swiss francs.

Linac2 is the machine that started more than a billion-trillion protons on trajectories that led to discoveries including the W and Z bosons, the creation of antihydrogen and the completion of the long search for the Higgs boson. On 12 November, Linac2 was switched off and will now be decommissioned as part of a major upgrade to the laboratory's accelerator complex (*CERN Courier* October 2017 p32). Its design, operation and performance have been key factors in the success of CERN's scientific programme and paved the way to its successor, Linac4, which will take over the task of producing CERN's protons from 2020.

Image above: The radio-frequency tanks of CERN's freshly installed Linac2 in 1979.

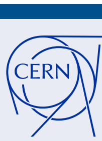
The decision to build Linac2 was taken in October 1973, with the aim to provide a higher-intensity proton beam compared to the existing Linac1 machine. Linac1 had been the original injector both to the PS when it began service in 1959, and to its booster (the PSB) when it was added to the chain in 1972. However, Linac1 was limited in the intensity it could provide, and the only way to higher intensity was for an entirely new construction.

Forward thinking

Linac2's design parameters were chosen to comfortably exceed the nominal PSB requirements, providing a safety margin during operation and for future upgrades. Furthermore, it was decided to install the linac in a new building parallel to the Linac1 location instead of in the Linac1 tunnel. This avoided a long shut-down for installation and commissioning, and ensured that Linac1 was available as a back-up during the first years of Linac2 operation.

Linac2's proton source was originally a huge 750 kV Cockcroft–Walton generator located in a shielded room, separate from the accelerator hall (figure 1), which provided the pre-acceleration to the entrance of the 4 m-long low energy beam transport line (LEBT). This transport line included a bunching system made of three RF cavities, after which protons were fed to the main accelerator: a drift-tube linac (DTL) that had many improvements with respect to the Linac1 design and became a standard for linacs at the time. The three accelerating RF "tanks", increasing the beam energy up to 10.3, 30.5 and 50 MeV, respectively, with a total length of 33.3 m, were made of mild steel co-laminated with a copper sheet, with the vacuum and RF sealing provided by aluminium wire joints.

The RF system is of prime importance for the performance of



CERN-AC-7602012

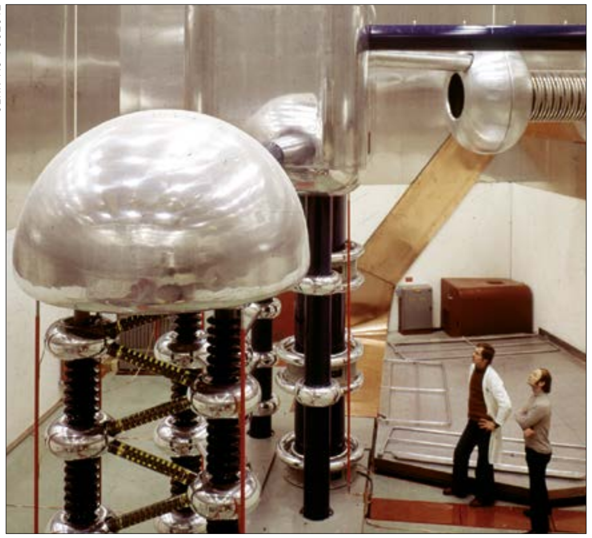


Fig. 1. Initially serving Linac2 was the 750 kV Cockcroft–Walton generator, source and accelerating column.

CERN-EX-0804060-03

Fig. 2. The Linac2 RFQ pre-injector and duoplasmatron proton source attached to the machine's RF tanks, photographed in 2008.

linear accelerators. For Linac2, the amplifiers had to provide a total RF power of 7.5 MW just to accelerate the beam. The RF amplifiers were based on the Linac1 design principles, with larger diameters in order to safely deliver the higher power, and the RF tube was the same triode already used for most of the Linac 1 amplifiers.

The most significant upgrade to Linac2, which took place during the 1992/1993 shutdown, was the replacement of the 750 kV Cockcroft–Walton generator and of the LEBT with a new RF quadrupole (RFQ) only 1.8 m long, capable of bunching, focusing and accelerating the beam in the same RF structure. The RFQ was a new invention of the early 1980s that was immediately adopted at CERN: after the successful construction of a prototype RFQ for Linac1 (which at the time was still in service), the development of a record-breaking high-intensity RFQ for Linac2, capable of delivering to the DTL a current of 200 mA, started in 1984. The prototype high-current RFQ was commissioned on a test stand in 1989, and the replacement of the Linac2 pre-injector was officially approved in 1990.

Gearing up for the LHC

The main motivation for the higher current of Linac2 was to prepare the CERN injectors for the LHC, which was already in progress. It was clear that the LHC would require unprecedented beam brightness (intensity per emittance) from the injector chain, and one of the options considered was to go to single-turn injection into the PSB of a high-current linac beam to minimise emittance growth. This, in turn, required the highest achievable current from the linac. Another motivation for the replacement was the simpler operation and maintenance of the smaller RFQ compared with the large Cockcroft–Walton installation.

Construction of the new RFQ (figure 2) started soon after approval, and the new "RFQ2" system was installed at Linac2 during the normal shut-down in 1992/1993. Commissioning of the RFQ2 with

CERN PhotoLab

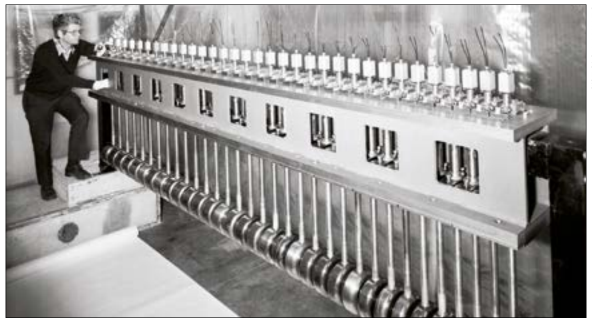


Fig. 3. The inner structure of Linac2, showing drift tubes hanging on stems under a rigid support structure that was mounted inside the lowest-energy Linac2 RF tank.

Linac2 took a few weeks, and the 1993 physics run started with the new injector. Reaching the full design performance of the RFQ took a few years, mainly due to the slow cleaning of the surfaces that at first limited the peak RF fields possible inside the cavity. After the optics in the long transfer line were modified, the goal of 180 mA delivered to the PSB was achieved in 1998 – and this still ranks as the highest intensity proton beam ever achieved from a linac.

Throughout its life, Linac2 has undergone many upgrades to its subsystems, including major renovations of the control systems in 1993 and 2012, the exchange of more than half its magnet power supplies to more modern units (although a large number were still the same ones installed in the 1970s) and renovation of the RFQ and vacuum-control systems. Nevertheless, at its core, the three DTL RF cavities that are the backbone of the linac remained unchanged since their construction, as were more than 120 electromagnetic quadrupoles sealed in the drift tubes that have each pulsed more than 700 million times without a single magnet failure (figure 3).

CERN-PHOTO-201704-093-3

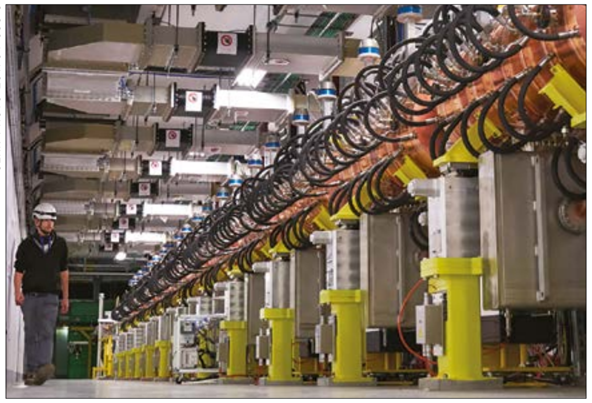


Fig. 4. A section of the new Linac4, which replaces Linac2.

Despite the performance and reliability of Linac2, the performance bottleneck of the injection chain for the LHC moved to the injection process of the PSB, which could only be resolved with a higher injection energy. This meant increasing the energy of the linac. At the time this was being considered, around a decade ago, Linac2 was already reaching 30 years of operation, and basing a new injector on it would have required a major consolidation effort. So the decision was made to move to a new accelerator called Linac4 (the name Linac3 is taken by an existing CERN linac that produces ions), which meant a clean slate for its design. Linac4 (figure 4) not only injects into the PSB at the higher energy of 160 MeV, but also switches to negative hydrogen-ion beam acceleration, which allows higher intensities to be accumulated in the PSB after removing the excess electrons.

As was the case when Linac2 took over from Linac1, Linac4 has been built in its own tunnel, allowing construction and commissioning to take place in parallel to the operation of Linac2 for the LHC (*CERN Courier* January/February 2018 p19). In connecting Linac4 to the PSB, some of the Linac2 transfer line will be dismantled to make space for additional shielding. But the original source, RFQ and three DTL cavities will remain in place for now – even if there is no possibility of their serving as a back-up once the change to Linac4 is made. As for the future of Linac2, hopefully you might one day be able to find part of the accelerator on display somewhere on the CERN site, so that its place in history is not forgotten.

Résumé

L'histoire de mille milliards de milliards de protons

Le Linac2 a fourni des protons au CERN depuis 1978. C'est cette machine qui a lancé plus de mille milliards de milliards de protons sur des trajectoires qui allaient mener à des découvertes, comme celles des bosons W et Z, à la création de l'antihydrogène, et à l'achèvement de la longue quête du boson de Higgs. Le Linac2 a été arrêté définitivement le 12 novembre, dans le cadre de l'importante amélioration du complexe d'accélérateurs du CERN qui va avoir lieu.

Richard Scrivens and **Maurizio Vretenar**, CERN.

Expedition

Cosmic research poles apart

Two independent groups are going to Earth's extremes to make unprecedented measurements for physics, education and the environment.

The Nanuq *photographed by a drone as it crossed the Greenland Sea from Iceland to Svalbard. (Image credit: Polarquest2018/M Struik.)*

Every second, each square metre of the Earth is struck by thousands of charged particles travelling from deep space. It is now more than a century since cosmic rays were discovered, yet still they present major challenges to physics. The origin of high-energy cosmic rays is the biggest mystery, their energy too high to have been generated by astrophysical sources such as supernovae, pulsars or even black holes. But cosmic rays are also of interest beyond astrophysics. Recent studies at CERN's CLOUD experiment, for example, suggest that cosmic rays may influence cloud cover through the formation of new aerosols, with important implications for the evolution of Earth's climate.

This year, two independent missions were mounted in the Arctic and in Antarctica – Polarquest2018 and Clean2Antarctica – to understand more about the physics of high-energy cosmic rays. Both projects have a strong educational and environmental dimension, and are among the first to measure cosmic rays at such high latitudes.

Geomagnetic focus

Due to the shape of the geomagnetic field, the intensity of the charged cosmic radiation is higher at the poles than it is in equatorial regions. At the end of the 1920s it was commonly believed that cosmic rays were high-energy neutral particles (i.e. gamma rays), implying that the Earth's magnetic field would not affect cosmic-ray intensity. However, early observations of the dependence of the cosmic-ray intensity on latitude rejected this hypothesis, showing that cosmic rays mainly consist of charged particles and leading to the first quantitative calculations of their composition.

The interest in measuring the cosmic-ray flux close to the poles is related to the fact that the geomagnetic field shields the Earth from low-energy charged cosmic rays, with an energy threshold (geomagnetic cut-off) depending on latitude, explains Mario Nicola Mazziotta, an INFN researcher and member of the Polarquest2018 team. "Although the geomagnetic cut-off decreases with increasing latitude, the cosmic-ray intensity at Earth reaches its maximum at latitudes of about 50–60°, where the cut-off is of a few GeV or less, and then seems not to grow anymore with latitude. This indicates that cosmic-ray intensity below a given energy is suppressed, due to solar effects, and makes the study of cosmic rays near the polar regions a very useful probe of solar activity."

Polarquest2018 is a small cosmic-ray experiment that recently completed a six-week-long expedition to the Arctic Circle, on board a 18 m-long boat called *Nanuq* designed for sailing in extreme regions. The boat set out from Isafjordur, in North-East Iceland, on 22 July, circumnavigating the Svalbard archipelago in August and arriving in Tromsø on 4 September. The Polarquest2018 detectors reached 82 degrees north, shedding light on the soft component of cosmic rays trapped at the poles by Earth's magnetic field.

Polarquest2018 is the result of the hard work of a team of a dozen people for more than a year, in addition to enthusiastic support from many other collaborators. Built at CERN by school students from Switzerland, Italy and Norway, Polarquest2018 encompasses three scintillator detectors to measure the cosmic-ray flux at different latitudes: one mounted on the *Nanuq*'s deck and two others installed in schools in Italy and Norway. The detectors had to operate with the limited electric power (12 W) that was available on board, both recording impinging cosmic rays and receiving GPS signals to timestamp each event with a precision of a few tens of nanoseconds. The detectors also had to be mechanically robust to resist the stresses from rough seas.

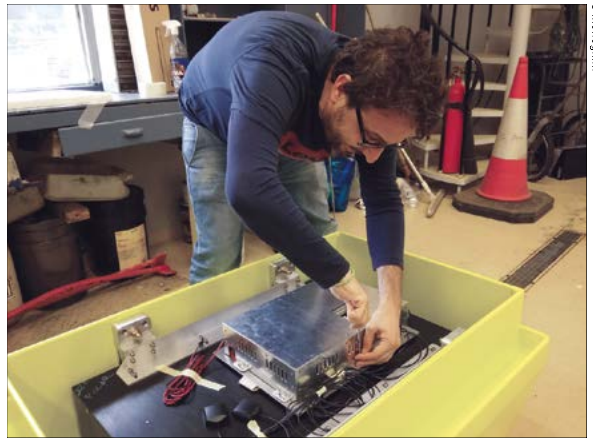
The three Polarquest2018 detectors join a network of around 60 others in Italy called the Extreme Energy Events – Science Inside Schools (EEE) experiment, proposed by Antonino Zichichi in 2004 and presently co-ordinated by the Italian research institute Centro Fermi in Rome, with collaborators including CERN, INFN and various universities. The detectors (each made of

Expedition

Polarquest2018/M Struik.

The Nanuq *stranded on rocks in uncharted waters near Svalbard.*

S Meneghini



Marco Garbini inspecting the Polarquest2018 detector in Iceland.

three multigap resistive plate chambers of about 2 m^2 area) were built at CERN by high-school students and the large area of the EEE enables searches for very-long-distance correlations between cosmic-ray showers.

A pivotal moment in the arctic expedition came when the *Nanuq* arrived close to the south coast of the Svalbard archipelago and was sailing in the uncharted waters of the Recherche Fjord. While the crew admired a large school of belugas, the boat struck the shallow seabed, damaging its right dagger board and leaving the craft perched at a 45° incline. The crew fought to get the *Nanuq* free, but in the end had to wait almost 12 hours for the tide to rise again. Amazingly, explains Polarquest2018 project leader Paola Catapano of CERN, the incident had its advantages. "It allowed the team to check the algorithms used to correct the raw data on cosmic rays for the inclination and rolling of the boat, since the data clearly showed a decrease in the number of muons due to a reduced acceptance."

Analysis of the Polarquest2018 data will take a few months, but preliminary results show no significant increase in the cosmic-ray flux, even at high latitudes. This is contrary to what one could naively expect considering the high density of the Earth's magnetic field lines close to the pole, explains Luisa Cifarelli, president of Centro Fermi in Rome. "The lack of increase in the cosmic flux confirms the hypothesis formulated by Lamaitre in 1932, with much stronger experimental evidence than was available up to now, and with data collected at latitudes where no published results exist," she says. The Polarquest2018 detector has also since embarked on a road trip to measure cosmic rays all along the Italian peninsula, collecting data over a huge latitude interval.

The hunt for the long-lost *Italia* airship

Polarquest2018 was more than a science experiment, it was also a historical expedition: an attempt to reach, for the first time, the location where the historic airship *Italia* crashed into the ice about 120 km northeast of Nordaustlandet, Svalbard, on its return journey from the first airborne circling of the North Pole in 1928. Several survivors and one fatality were left on the floating ice awaiting rescue, and six more crew were trapped in the drifting airship shell. But the shell and the crew members aboard it have never been found. Taking advantage of the lack of ice in the area for the first time in centuries, Polarquest2108 searched a wide region for metallic wreckage using an experimental 3D multi-beam sonar from NORBIT Subsea. It was the first documented attempt at locating the wreck in 90 years and team is still analysing the data in the most likely crash area.

Heading south

Meanwhile, 20,000 km south, a Dutch expedition to the South Pole called Clean2Antarctica has just got under way, carrying a small cosmic-ray experiment from Nikhef on board a vehicle called Solar Voyager. The solar-powered cart, built from recycled 3D-printed household plastics, will make the first ground measurements in Antarctica of the muon decay rate and of charged particles from extensive-air cosmic-ray showers. Cosmic rays will be measured by a roof-mounted scintillation device as the cart makes a 1200 km, six-week-long journey from the edge of the Antarctic icefields to the geometric South Pole.

The team taking the equipment across the Antarctic to the South Pole comprises mechanical engineer Ter Velde and his wife Liesbeth, who initiated the Clean2Antarctica project and are both active ocean sailors. Back in the warmer climes of the Netherlands,

Clean2Antarctica

A trial run of Clean2Antarctica's Solar Voyager in Iceland.

M Kraan / Nikhef

Solar Voyager takes shape in a workshop in the Netherlands.

researchers from Nikhef will remotely monitor for any gradients in the incoming particle fluxes as the magnetic field lines are converging closer to the pole. In theory, the magnetic field will funnel charged particles from the high atmosphere to the Earth's surface, leading to higher fluxes near the pole. But the incoming muon signal should not be affected, as this is produced by high-energy particles producing air showers of charged particles, explains Nikhef project scientist Bob van Eijk. "But this is experimental physics and a first, so we will just do the measurements and see what comes out," he says.

The scintillation panel used is adapted from the HiSPARC rooftop cosmic-ray detectors that Nikhef has been providing in high schools in the Netherlands, the UK and Denmark for the past 15 years. Under professional supervision, students and teachers build these roof-box-sized detectors themselves and run the detection programme and data-analysis in their science classes. Some 140 rooftop stations are online and many thousands of pupils have been involved over the years, stimulating interest in science and research.

Pristine backdrop

The panel being taken to Antarctica is a doubled-up version that is half the usual area of the HiSPARC panels due to strict space restrictions. Two gyroscope systems will correct for any changes in the level of the panel while traversing the Antarctic landscape. All the instruments are solar powered, with the power coming from photovoltaic panels on two additional carts pulled by the main electric vehicle. The double detection depth of the panels will allow for muon-decay detection by photomultiplier tubes as well as regular cosmic-ray particles such as electrons and photons. Data from the experiment will be relayed regularly by satellite from the Solar Voyager vehicle so that analysis can take place in parallel, and will be made public through a dedicated website.

The Clean2Antarctic expedition set off in mid-November from Union Glacier Camp station near the Antarctic Peninsula. It is sponsored by Dutch companies and from crowd funding, and has benefitted from extensive press and television coverage. The trip will take the team across bleak snow planes and altitudes up to 2835 m and, despite being the height of Antarctic summer, temperatures could be down to –30 °C. The mission aims to use the pristine backdrop of Antarctica to raise public awareness about waste reduction and recycling.

"This is one of the rare occasions that a scientific outreach programme, with genuine scientific questions targeting high-school students as prime investigators, teams up with an idealist group that tries to raise awareness on environmental issues regarding circular economy," says van Eijk. "The plastic for the vehicles was collected by primary-school kids, while three groups of young researchers formed 'think tanks' to generate solutions to questions about environmental issues that industrial sponsors/partners have raised." Polarquest2018 had a similar goal, and its MantaNet project became the first to assess the presence and distribution of microplastics in the Arctic waters north of Svalbard at a record latitude of 82.7° north. According to MantaNet project leader Stefano Alliani: "One of the conclusions already drawn by sheer observation is that even at such high latitudes the quantity of macro plastic loitering in the most remote and wildest beaches of our planet is astonishing."

Further reading

www.polarquest2018.org.
www.clean2antarctica.nl.

Résumé

La recherche cosmique sur les deux pôles

Deux groupes indépendants de physiciens sont partis au bout du monde pour réaliser des mesures inédites sur les rayons cosmiques. Les projets Polarquest2018 et Clean2Antartica visent à en apprendre davantage sur la physique des rayons cosmiques de haute énergie, au moyen de données collectées aux latitudes les plus élevées. Les deux projets ont une importante composante éducative : des élèves ont participé à leur préparation, et tous deux visent à sensibiliser le public sur les questions environnementales, avec en toile de fond les paysages immaculés des pôles.

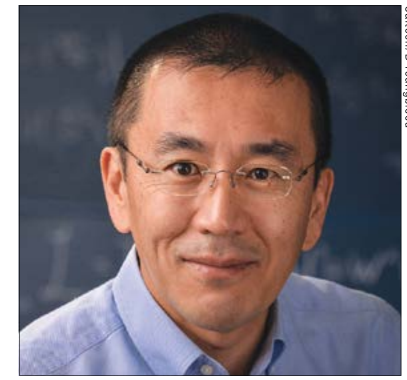
Matthew Chalmers, CERN, and **Martijn van Calmthout**, Nikhef.

Faces & Places

Appointments

Hirosi Ooguri is the new director of Kavli IPMU

The Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) at the University of Tokyo in Japan announced on 15 October the appointment of Hirosi Ooguri as its new director. The Kavli IPMU is one of Japan's most renowned research institutions, bringing together physicists, mathematicians and astronomers to address fundamental questions in the field. Ooguri, who bridges physics and mathematics, has extensive leadership experience as the founding director of the Walter Burke Institute for Theoretical Physics at Caltech and as president of the Aspen Center for Physics. He also received the 2018 Hamburg Prize for Theoretical Physics for his successful mathematical work on topological string theory and for making his research more publicly available (*CERN Courier* July/August 2018 p35).



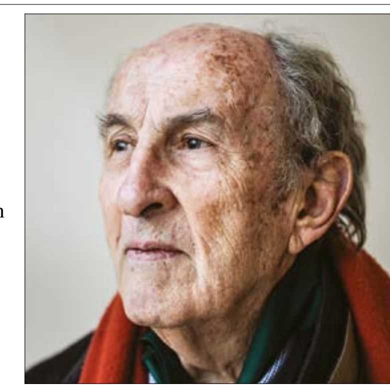
Caltech/B Youngblood

Hirosi Ooguri will take over at Kavli IPMU.

Ooguri will take over from Hitoshi Murayama, who has served as the institute's founding director for 11 years. Michael Turner, the director of the Kavli Institute for Cosmological Physics at the University of Chicago, said of the succession: "Hitoshi Murayama succeeded in creating the IPMU as a world centre, and six years ago brought IPMU into the Kavli family of world-leading institutes. With the appointment of Hirosi Ooguri, he has handed off IPMU to another visionary."

Petroff nominated director of Brazilian light source

Yves Petroff, a leading expert on synchrotron radiation, has been nominated as director of the Brazilian Synchrotron Light Laboratory LNLS, where a major new synchrotron called Sirius is about to enter operations. Starting with six beamlines in the first year of operation (2019), six more in the second and six others in the third, Sirius will open new perspectives for research in materials science, nanotechnology, biotechnology and environmental science.



ESRF/E Bouy

Synchrotron-radiation expert Yves Petroff.

Petroff directed the Grenoble-based European Synchrotron Radiation Facility (ESRF) during the facility's inaugural years, managing an increase in the number of ESRF beamlines from 15 in 1994 to 40 in 1998 (see feature on p17). On leaving the ESRF in 2001, Petroff took up an advisory role at LNLS and remained close to the facility in the ensuing years. The Sirius building is almost finished and the booster and storage ring are under installation, aiming for user operation in July 2020. "Sirius is a miracle for Brazil and it will have taken just over four years between ground-breaking and the first beam," Petroff said.

Awards

APS announces 2019 prize and award winners

The American Physical Society (APS) has awarded its prizes and awards for 2019, several of which are devoted to the fields of high-energy and nuclear physics.

The W K H Panofsky Prize in Experimental Particle Physics went to Sheldon Leslie Stone of Syracuse University "for transformative contributions to flavour physics and hadron spectroscopy, in particular through intellectual leadership on detector construction and analysis on the CLEO and Large Hadron Collider beauty (LHCb) experiments, and for the long-standing, deeply influential advocacy for flavour physics at hadron colliders." Stone served as coordinator for the upgrade of LHCb from 2008 until 2011, and currently the Syracuse group is leading the construction of the silicon-strip tracking component of the upgrade.

Also in the experimental field, the Henry Primakoff Award for Early-Career Particle Physics was granted to Nhan Tran from Fermilab, citing his wide-ranging contributions to the CMS experiment, including the development of a novel pileup-subtraction method at the LHC, and the use of jet substructure for the analysis of high-energy collisions. His work contributed, among other things, to the discovery and characterisation of the Higgs boson.

The Robert R Wilson Prize for Achievement in the Physics of Particle Accelerators went to Toshiki Tajima at the University of California, Irvine, "for the invention and leading the first realisation of laser wakefield acceleration, which opened the way to compact acceleration applications such as ultrafast radiolysis, brilliant x-rays, intra-operative radiation therapy, wakefield beam dump, and high-energy cosmic acceleration." (*CERN Courier* October 2018 p7).

The J J Sakurai Prize for Theoretical Particle Physics is shared between Lisa Randall of Harvard University and Raman Sundrum of the University of Maryland, College Park. The citation noted their creative contributions to physics beyond the Standard Model, in particular the theoretical discovery that warped extra dimensions of space can solve the hierarchy puzzle, which has had a tremendous impact on searches at the LHC.

In the nuclear-physics area, Barry R Holstein of the University of Massachusetts, Amherst, won the Herman Feshbach Prize in Theoretical Nuclear Physics "for seminal theoretical studies of fundamental symmetries in nuclei, including radioactive nuclear decays, parity-violating nucleon–nucleon interactions, and chiral dynamics of mesons and baryons." The Tom W Bonner Prize in Nuclear Physics, meanwhile, was awarded to Barbara V Jacak from the University of California, Berkeley and Lawrence Berkeley Laboratory "for leadership in the discovery and characterisation of the quark–gluon plasma, especially her contributions to the PHENIX experiment and its explorations of jets as probes."

On the gravitational physics and cosmology fronts, the Einstein Prize was awarded to Abhay Ashtekar of Pennsylvania State University, State College, "for numerous and seminal contributions to general relativity, including the theory of black holes, canonical quantum gravity and quantum cosmology," and the Julius Edgar Lilienfeld Prize awarded to Katherine Freese of the University of Michigan and Stockholm University "for ground-breaking research at the interface of cosmology and particle physics, and her tireless efforts to communicate the excitement of physics to the general public."

Other prizes and awards included the Abraham Pais Prize for History of Physics awarded to Helge Kragh of the Niels Bohr Institute, University of Copenhagen, "for influential contributions to the history of physics, especially analyses of cosmological theories and debates, the history of the quantum physics of elementary particles and the solid state, and biographical studies of Paul Dirac and Niels Bohr, and his early quantum atom," and the Distinguished Lectureship Award on the Applications of Physics awarded to Cynthia Keppel of the Thomas Jefferson National Accelerator Facility "for pioneering work in proton therapy and for the promotion of the applications of physics to both experts and non-experts."

Clockwise from top left: Stone, Tran, Tajima, Randall, Freese, Jacak, Holstein and Sundrum.

ATLAS recognises outstanding members

On 11 October the ATLAS collaboration celebrated the outstanding achievements of 15 of its collaboration members with an awards ceremony. Established in 2014, the Outstanding Achievement Awards give recognition to excellent contributions made to the collaboration in all areas, excluding physics analysis. This year's awards celebrated contributions to the measurement of jet energy and missing transverse momentum; the inner-tracker upgrade project; the development, deployment and commissioning of the trigger burst-stopper for the ATLAS level-1 endcap muon system; the online luminosity software; the commissioning of the level-1 Topo trigger; and software development and deployment.

"Within the ATLAS collaboration, huge efforts go into making the detector function seamlessly," says Jim Pilcher, awards committee chair. "We sought to reward the people who have made dramatic improvements to the operation and understanding of our detector, thus improving the quality of our measurements."

CERN

The winners of the 2018 ATLAS Outstanding Achievement Awards, together with ATLAS spokesperson Karl Jakobs (far left), awards committee chair Jim Pilcher and collaboration board chair Max Klein (right).

Events

CERN commemorates history of Berlin building

On 26 October, at a ceremony in Berlin, CERN in association with the Aktives Museum unveiled a plaque describing the history of a building owned by the CERN Pension Fund.

Number 16 Wallstrasse is an attractive building constructed in 1908 and acquired by cousins Jakob Berglas and Jakob Intrator in 1920. Following CERN's purchase of the building in 2015, Intrator's granddaughter, Joanne, a New York-based psychiatrist, contacted CERN to explain what happened after her grandfather and uncle acquired the building, and to ask that a commemorative plaque be placed to highlight its history.

Berglas and Intrator were Jewish, and although they escaped the Nazis, their building was one of many taken from Jewish people in 1930s Berlin. Some years later, it was home to a printing company that produced Jewish Stars there in the summer of 1941: the infamous symbols sewn onto the clothes of Jewish people in the Third Reich.

Joanne Intrator and several members of the wider Intrator family took part in the ceremony, together with representatives of the German and Israeli governments, and senior representatives from CERN. "The history of CERN is closely connected with that of the Second World War," said CERN director for international relations, Charlotte Warakaulle. "Our laboratory was created as a reaction and as a contrast to what happened in Europe in the 1930s and 1940s. We owe our existence to the foresight and determination of scientists and politicians from many nations who shared a vision of reconciling a war-torn continent through culture, including science. We continue to live by this vision and to be inspired by it."

A Marsollier

Joanne Intrator, granddaughter of Jakob Intrator, and Charlotte Warakaulle, CERN's director for international relations, standing in front of the commemorative plaque.

CERN-PHOTO-201810-263-28

On 9 October, 42 companies from France came to CERN to take part in the annual France@CERN industry event. The firms spanned a large range of areas, from bolts and tubes to various instruments and devices for measurement, control and automation. Industries in member countries are of vital importance to CERN's projects, such as the LHC. In 2017, for example, more than 500 firms were involved as contractors and suppliers to CERN and its experiments, representing a total expenditure of more than 500 million Swiss francs.

Correction

The image on page 29 of the November issue depicts the KLOE-2 experiment, which recently concluded its data-taking campaign at the DAΦNE collider (*CERN Courier* June p8), not the AdA collider as stated in the caption of the print issue. AdA was of course the first electron–positron collider and, as one reader kindly pointed out, is now an exhibit at Italy's INFN Frascati National Laboratories (*CERN Courier* January/February 2014 p30).

CTA Observatory

Inauguration event in La Palma for the first prototype large-sized telescope LST-1.

First telescope on Cherenkov array site

More than 200 guests gathered on the island of La Palma, Spain, on 10 October to celebrate the inauguration of the first telescope for the Cherenkov Telescope Array (CTA), the next-generation ground-based gamma-ray observatory. The prototype large-sized telescope (LST-1) is the first of four LSTs to be located on the north site of the CTA in La Palma, later to be joined by 15 medium-sized telescopes.

Like the LHC, the CTA represents a major data challenge: it is expected to generate 100 petabytes of data by 2030. With more than 100 telescopes planned for the northern and southern hemispheres, the CTA will be the largest and most sensitive high-energy gamma-ray observatory.

MEETINGS

Theory event fuses physics and gender

CERN-PHOTO-201809-248-8

Some of the participants at the first workshop on high-energy theory and gender.

CERN hosted a workshop on high-energy theory and gender on 26–28 September. It was the first activity of the "Gen-HET" working group, whose goals are to improve the presence and visibility of women in the field of high-energy theory and increase awareness of gender issues (see p5).

Most of the talks in the workshop were on physics. Invited talks spanned the whole of high-energy theory, providing an opportunity for participants to learn about new results in neighbouring research areas at this interesting time for the field. Topics ranged from the anti-de-Sitter/conformal field theory (AdS/CFT) correspondence and inflationary cosmology to heavy-ion, neutrino and beyond-Standard Model physics.

Agnese Bissi (Uppsala University, Sweden) began the physics programme by reviewing the now-two-decades-old AdS/CFT correspondence, and discussing the use of conformal bootstrap methods in holography. Korinna Zapp (LIP, Lisbon, Portugal and CERN) then put three recent discoveries in heavy-ion physics into perspective: the hydrodynamic behaviour of soft particles; jet quenching; and surprising similarities between soft particle production in high-multiplicity proton–proton and heavy-ion collisions.

JiJi Fan (Brown University, USA) delved into the myriad world of beyond-the Standard Model phenomenology, discussing the possibility that the Higgs is "meso-tuned" but that there are no other light scalars. Elvira Gamiz (University of Granada, Spain) reviewed key features of lattice simulations for flavour physics and mentioned significant tensions with some experimental results that are as high as 3σ in certain B-decay channels. The theory colloquium, by Ana Achucarro (University of Leiden, Holland, and UPV-EHU Bilbao, Spain), was devoted to the topic of inflation, which still presents a major challenge to theorists.

The importance of parton distribution functions in an era of high-precision physics was the focus of a talk by Maria Ubiali (University of Cambridge, UK), who explained the state-of-the-art methods used. Reviewing key topics in cosmology and particle physics, Laura Covi (Georg-August-University Göttingen, Germany) then described how models with heavy R-parity violating supersymmetry lead to scenarios for baryogenesis and gravitino dark matter.

In neutrino physics, Silvia Pascoli (Durham University, UK) gave an authoritative overview of the experimental and theoretical status, while Tracy Slatyer (MIT, USA) did the same for dark matter, emphasising the necessity of search strategies that test many possible dark-matter models.

Closing the event, Alejandra Castro (University of Amsterdam, the Netherlands) talked about black-hole entropy and its fascinating connections with holography and number theory. The final physics talk, by Eleni Vyronidou (CERN), covered Standard Model effective field theory (SMEFT), which provides a pathway to new physics above the direct energy-reach of colliders.

The rest of the workshop centred on talks and discussion sessions about gender issues. The full spectrum of issues was addressed, a few examples of which are given here.

Julie Moote from University College London, UK, delivered a talk on behalf of the Aspires project in the UK, which is exploring how social identities and inequalities affect students continuing in science, while Marieke van den Brink from Radboud University Nijmegen, the Netherlands, described systematic biases that were uncovered by her group's studies of around 1000 professorial appointments in the Netherlands. Meytal Eran-Jona from the Weizmann Institute of Science, Israel, reviewed studies about unconscious bias and its implications for women in academia, and described avenues to promote gender equality in the field.

The last day of the meeting focused on actions that physicists can take to improve diversity in their own departments. For example, Jess Wade from Imperial College London, UK, discussed UK initiatives such as the Institute of Physics Juno and Athena SWAN awards, and Yossi Nir from the Weizmann Institute gave an inspiring account of his work on increasing female participation in physics in Israel. One presentation drawing on bibliometric data in high-energy theory attracted much attention beyond the workshop, as has been widely reported elsewhere.

This first workshop on high-energy theory and gender combined great physics, mentoring and networking. The additional focus on gender gave participants the opportunity to learn about the sociological causes of gender imbalance and how universities and research institutes are addressing them.

We are very grateful to many colleagues for their support in putting together this meeting, which received help from the CERN diversity office and financial support from the CERN theory department, the Mainz "cluster of excellence" PRISMA, Italy's National Institute for Nuclear Physics (INFN), the University of Milano-Bicocca, the ERC and the COST network.

Similar activities are planned in the future, including discussions on other scientific communities and minority groups.

● *Alessandra Gnecchi, CERN, and Marika Taylor, University of Southampton, on behalf of the conference organisers.*

Muon g-2 fans gather in Novosibirsk

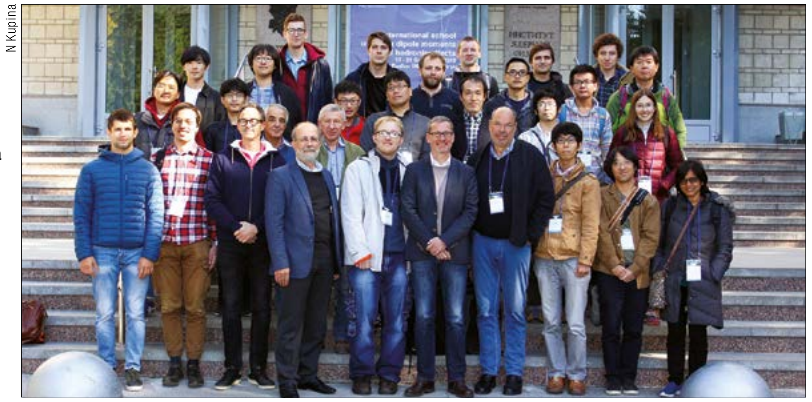
The Budker Institute of Nuclear Physics and the Novosibirsk State University co-hosted the first international school on the muon's dipole moments and hadronic effects in Novosibirsk, Russia, on 17–21 September. About 40 researchers from 20 institutions in Austria, China, Germany, Italy, Japan, Russia and South Korea discussed the various problems related to investigations of the muon's anomalous magnetic moment, g-2.

For more than 10 years, the large excess (more than 3.5 standard deviations) of the muon's anomalous magnetic moment over the Standard Model prediction measured by the muon g-2 experiment at the Brookhaven National Laboratory (BNL) in the US has caused great interest in the high-energy-physics community. With more than 1700 citations, the final publication of the muon g-2 collaboration has stirred numerous discussions on whether the excess could be due to new physics. A solution to the problem will require combined efforts from both theorists, to estimate more accurately hadronic effects on the muon's moment, and experimentalists, to perform new high-precision measurements.

The idea of the Novosibirsk school was to bring together two communities of researchers, one involved in making new direct measurements of the muon's moment at Fermilab in the US (*CERN Courier* September 2018 p9) and at J-PARC in Japan, and another measuring electron–positron annihilation into hadrons (BESIII, CMD-3 and SND collaborations) to be used in theoretical calculations of the hadronic effects.

The scientific programme of the school comprised five lecture courses. Yannis Semertzidis from the Institute for Basic Science in Daejeon, Korea, summarised the experimental situation with a review of the existing storage rings, a discussion of the statistical and systematic uncertainties of such measurements, and ideas for new experiments.

N Kupina



Participants at the first international school on muon g-2 in Novosibirsk.

Achim Denig from the University of Mainz, Germany, described experiments on electron–positron annihilation into hadrons, based on the so-called scan method, mostly developed in Novosibirsk, used in the CMD-3 and SND experiments as well as on the initial-state radiation method extensively used in the BaBar, Belle, BESIII and KLOE experiments. A comprehensive review of modern detectors was given by Stephan Paul from the Technical University of Munich, Germany.

Massimo Passera from the University of Padova, Italy, focused on aspects of the Standard Model that are directly related to the magnetic moments of leptons generally. He spoke about the QED, electroweak and hadronic contributions to lepton magnetic moments, explaining their hierarchy and accuracy, and covered both the traditional dispersive approach and novel methods based on lattice calculations. Josef Pradler from the Institute of High Energy Physics in Vienna, Austria, spoke about attempts to explain the problem by invoking dark matter.

The programme also comprised review talks on searches for axions, the g-2/EDM experiment at J-PARC, which aims to measure the muon's anomalous moment and electric dipole moment (EDM) with ultra-high precision, and future facilities at the Budker Institute. The latter include the Super-charm-tau factory to study properties of charmed hadrons and tau leptons with unprecedented accuracy, and the Mumutron, a low-energy electron–positron collider to study dimuonium.

Finally, of the 18 additional brief presentations, most were devoted to the J-PARC g-2/EDM experiment, and three featured the MuSEUM experiment, which will provide a new high-precision measurement of the hyperfine structure of muonium. There were also talks about the already running muon g-2 experiment at Fermilab, and about analyses of hadronic data from the CMD-3 detector.

The success of the school led to the decision to make it a regular event, to be held every other year in one of the relevant research centres. The University of Mainz has offered to host the 2020 school.

● *Simon Eidelman and Anna Vinokurova, Budker Institute and Novosibirsk State University.*

Tau physics focus in Amsterdam

The 15th International Workshop on Tau Lepton Physics (TAU2018) was held at Vondelkerk, a former church in the centre of Amsterdam, the Netherlands, on 24–29 September. The focus of the series is on the physics of the tau lepton, its neutrino and related processes, and the goal is to stimulate discussions between theorists and experimentalists and to review recent progress in the field. This year's edition attracted about 120 participants from all over the world, and the programme comprised 90 invited and contributed talks, half of which were given by theorists. The workshop featured new results from both high-energy experiments (such as ATLAS, CMS and LHCb) and low-energy experiments (BESIII and others), from B factories such as Belle II, and recent results from muon g-2 and neutrino-oscillation experiments.

New measurements of tau decays with kaons or pions in the final state were presented by both the Belle and the BaBar collaborations, followed by a discussion on the extraction of the coupling V_{us} between the up quark and the strange quark. The Belle II collaboration presented its first data plots, showing good progress with the commissioning of the Belle II detector and beautiful signals of J/ψ, K_S, π^0 and $\tau \rightarrow 3\pi\nu$ decays. Meanwhile, the BESIII collaboration is on track to obtain the single most precise measurement of the tau mass. The LHC-experiment collaborations presented searches for physics beyond the Standard Model (BSM) and measurements of Standard Model parameters. On the BSM front, a wide range of final states with tau leptons were explored in the pursuit of lepton-flavour-violating processes and other BSM phenomena, but no significant deviations from the Standard Model have been observed. On the Standard Model measurements front, highlights included the polarisation in $Z \rightarrow \tau\tau$ decays and the Higgs–tau coupling. Possible benefits of machine-learning tools in particle-physics measurements were also addressed.

The programme also included subjects such as hadron cross-section measurements at electron–positron colliders, lepton-flavour-universality puzzles in meson decays, searches for lepton-flavour violation in tau, muon and Z decays, and review talks on future experiments. The recent LHCb measurements indicating lepton non-universality in certain B-meson decays remain a hot topic, and discussions at the meeting suggested looking for possible connections between the LHCb results and high-momenta measurements and direct BSM searches at the LHC.

A session dedicated to neutrinos showed the power of neutrino physics to study BSM physics. The recent data from the LSND and MiniBooNE experiments, which could indicate the existence of sterile neutrinos, keep challenging results from other neutrino experiments, and the explanation for this has yet to be found. A session on muon g-2 covered the preparation of new experiments and improved predictions of g-2 based on lattice calculations. The BESIII collaboration presented new results on the light-by-light scattering contribution to g-2 and the VEPP-2000 collaboration showed improved measurements of hadronic effects on g-2. A session on quantum chromodynamics revisited the extraction of the strength of the parameter α_S from ALEPH data, with lively discussions focused on duality violation.

Finally, muon lepton-flavour-violation experiments are on the verge of delivering highly anticipated data on lepton-flavour-violating decays (in some cases, they are expected to improve existing measurements by a factor of 1000). The programme ended with presentations on future experiments at planned accelerators in China, Europe and Japan, as well as future neutrino and muon experiments. Simon Eidelman presented the conference's highlights in his stimulating summary talk. With many new results expected, the next edition of the workshop, TAU2020, promises to be a very interesting meeting.

● *Olya Igonkina, Nikhef and Radboud Universiteit Nijmegen, and Robert Fleischer, Nikhef and Vrije Universiteit Amsterdam.*

M Kraan, Nikhef

The TAU2018 participants in front of the conference venue Vondelkerk, a former church.

Exploring quantum computing for high-energy physics

The ambitious upgrade programme for the Large Hadron Collider (LHC) will result in significant information and communications technology (ICT) challenges over the next decade and beyond. It is therefore vital that members of the HEP research community keep looking for innovative computing technologies so as to continue to maximise the discovery potential of the world-leading research infrastructures at their disposal (*CERN Courier* November 2018 p5).

On 5–6 November, CERN hosted a first-of-its kind workshop on quantum computing in high-energy physics (HEP). The event was organised by CERN openlab, a public–private partnership between CERN and leading ICT companies established to accelerate the development of computing technologies needed by the LHC research community.

More than 400 people followed the workshop, which provided an overview of the current state of quantum-computing technologies. The event also served as a forum to discuss which activities within the HEP community may be amenable to the application of quantum-computing technologies.

"In CERN openlab, we're always looking with keen interest at new computing architectures and trying to understand their potential for disrupting and improving the way we do things," says Alberto Di Meglio, head of CERN openlab. "We want to understand which computing workflows from HEP could potentially most benefit from nascent quantum-computing technologies; this workshop was the start of the discussion."

Significant developments are being made in the field of quantum computing, even if today's quantum-computing hardware has not yet reached the level at which it could be put into production. Nevertheless, quantum-computing technologies are among those that hold future promise of substantially speeding up tasks that are computationally expensive.

"Quantum computing is no panacea, and will certainly not solve all the future computing needs of the HEP community," says Eckhard Elsen, CERN's director for research and computing. "Nevertheless, quantum computers are starting to be available; a breakthrough in the number of qubits could emerge at any time. Fundamentally rethinking our algorithms may appear as an interesting intellectual challenge today, yet may turn out as a major benefit in addressing computing challenges in the future."

The workshop featured representatives of the LHC experiments, who spoke about how computing challenges are likely to evolve as we approach the era of the High-Luminosity LHC. There was also discussion of work already undertaken to assess the feasibility of applying today's quantum-computing technologies to problems in HEP. Jean-Roch Vlimant provided an overview of their recent work at the California Institute of Technology, with collaborators from the University of Southern California, to solve ▷

an optimisation problem related to the search for Higgs bosons. Using an approach known as quantum annealing for machine learning, the team demonstrated some advantage over traditional machine-learning methods for small training datasets. Given the relative simplicity of the algorithm and its robustness to error, they report, this technique may find application in other areas of experimental particle physics, such as real-time decision making in event-selection problems and classification in neutrino physics.

Several large-scale research initiatives related to quantum-computing technologies were presented at the event, including the European Union's €1 billion Quantum Technologies Flagship project, which involves universities and commercial partners across Europe. Presentations were also given of ambitious programmes in the US, such as the Northeast Quantum Systems Center at Brookhaven National Laboratory and the Quantum Science Program at Fermilab, which includes research areas in superconducting quantum systems, quantum algorithms for HEP, and computational problems and theory.

A Purcell

Eckhard Elsen, CERN's director for research and computing, speaking at the quantum computing in high-energy physics event.

Perhaps most importantly, the workshop brought members of the HEP community together with leading companies working on quantum-computing technologies. Intel, IBM, Strangeworks, D-Wave, Microsoft, Rigetti and Google all presented their latest work in this area at the event. Of these companies, Intel and IBM are already working closely with CERN through CERN openlab. Plus, Google also announced at the event that they have signed an agreement to join CERN openlab.

"Now is the right time for the HEP community to get involved and engage with different quantum-computing initiatives already underway, fostering common activities and knowledge sharing," says Federico Carminati, CERN openlab CIO and chair of the event. "With its well-established links across many of the world's leading ICT companies, CERN openlab is ideally positioned to help drive this activity forward. We believe this first event was a great success and look forward to organising future activities in this exciting area."

Recordings of the talks given at the workshop are available via the CERN openlab website at: openlab.cern.

● *Andrew Purcell, CERN.*

Halfway to high luminosity

CERN-PHOTO-201810-268-26

Participants at the High-Luminosity LHC collaboration's annual meeting.

The High-Luminosity LHC (HL-LHC) has reached its halfway point. The upgrade project was launched eight years ago and is scheduled to start up in 2026, following major interventions to the CERN accelerator complex. From 15 to 18 October, representatives of the institutes contributing to the HL-HLC gathered at CERN for the 8th annual meeting of the HL-LHC to assess progress as the project moves from prototyping to the series production phase for much of the equipment.

The HL-LHC annual meeting is a chance to conduct a global review of the project. The civil-engineering work has progressed since it began in the spring: excavations have reached a depth of 30 m at Point 1 (ATLAS) and 25 m at Point 5 (CMS). The two 80 m shafts should be fully excavated by the beginning of 2019. As for the accelerator, one of the key tasks is the production of around 100 magnets of 11 different types. Some of these, notably the main superconducting quadrupole magnets that will replace the LHC's triplets and focus the beams very strongly before they collide, are made from the conductor niobium tin, which is particularly difficult to work with. The short prototype phase is already nearing completion for the quadrupole magnets: the long (7.15 m) quadrupoles are being produced at CERN, while shorter (4.2 m) quadrupoles are being developed in the framework of the US LHC-AUP (LHC Accelerator Upgrade Project) collaboration. Several short prototypes have already reached the required intensities on both sides of the Atlantic.

New dipole magnets at the interaction points, which divert the beams before and after the collision point, are being developed in Japan and Italy. One short model has been successfully tested at the KEK laboratory in Japan and a second is in the process of being tested. INFN in Italy is also assembling a short model. Finally, progress is being made on the development of the corrector magnets at CERN and in Spain (CIEMAT), Italy (INFN) and China (IHEP), with several prototypes already tested. In 2022, a test line will be installed at CERN's SM18 hall to test the first magnet chains.

One of the major successes of 2018 is the installation in the Super Proton Synchrotron (SPS) of a test bench with an autonomous cryogenic unit. The test bench houses two DQW (double-quarter wave) crab cavities, one of two designs under study (*CERN Courier* May 2018 p18). The two cavities rotated the proton bunches as soon as the tests began in May, marking a world first. The construction of the DQW cavities will continue while the second architecture, the radiofrequency dipole, is being developed in the US.

Many other developments were presented during the symposium: new collimators have been tested in the LHC; a beam absorber for the injection points from the SPS was tested over the summer and will be installed during the LHC's second long shutdown; a demonstrator for a magnesium-diboride superconducting link is currently being validated; and studies have been undertaken to test and adjust the remote alignment of all the equipment in the interaction regions.

Over the four days that the meeting took place, some 180 presentations covered a wide range of technologies developed for the HL-LHC and beyond.

● *Corinne Pralavorio, CERN.*

OBITUARIES

Leon Lederman 1922–2018

Leon Lederman, a pioneering US experimental particle physicist who shared the Nobel Prize in Physics for the discovery of the muon neutrino, passed away on 3 October at the age of 96. Lederman's career spanned more than 60 years and had a major impact in putting the Standard Model of particle physics on empirical ground.

Lederman was born in New York City on 15 July 1922 to Russian–Jewish immigrant parents. He graduated from City College of New York with a degree in chemistry in 1943, but had already fallen under the influence of future physicists including Isaac Halpern and Martin Klein. After graduating he spent three years in the US Army, where he rose to the rank of 2nd lieutenant in the signal corps. In 1946 he entered the graduate school of physics at Columbia University, chaired by I I Rabi, and in 1951 he received his PhD in particle physics.

During the 1950s Lederman contributed to two major physics results: the discovery of the long-lived neutral K meson at Brookhaven National Laboratory's 3 GeV Cosmotron in 1956; and, in 1957, the observation of parity violation in the pion–muon–electron decay chain at the Nevis 385 MeV synchrocyclotron at Columbia University. The latter experiment provided the first measurement of the muon magnetic moment, opening a path to the "g-2" experiment at CERN's first accelerator, the synchrocyclotron. In 1958, shortly after he was promoted to professor, Lederman took his first sabbatical at CERN where he contributed to the organisation of the g-2 experiment. This programme lasted for almost two decades and involved many prominent CERN physicists, including Georges Charpak, Emilio Picasso, Francis Farley, Johannes Sens and Antonino Zichichi.

Lederman's crowning achievement came in 1962 with the co-discovery of the muon neutrino at Brookhaven's Alternating Gradient Synchrotron (AGS). For this work, he shared the 1988 Nobel Prize in Physics with Jack Steinberger and the late Melvin Schwartz "for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino." The experiment used a spark chamber to show that the neutrinos from beta decay and the neutrinos from muon decay were different, leading to the first direct observation of muon neutrinos and marking a key step in the understanding of weak interactions. Steinberger, who joined CERN six years after the muon-neutrino discovery and is now 97, has fond memories of his collaboration with Lederman. "What I remember about Leon is that we worked together at the same labs, at Nevis and at Brookhaven, and we got the Nobel Prize together, with Mel Schwartz. It was for a non-trivial experiment. He was a good friend. I'm very sad that he's gone."

FNAL

Pioneering particle physicist Leon Lederman.

At the end of the 1960s, in another experiment at the AGS, Lederman discovered the production of muon pairs with a continuous mass distribution in proton–nucleon collisions – an unexpected phenomenon that was soon interpreted as the result of quark–antiquark annihilation. As a follow-up to this experiment, in collaboration with physicists from CERN, Columbia and Rockefeller universities, Lederman proposed to study the production of electron–positron pairs at CERN's Intersecting Storage Rings (ISR), which started operation in 1971. The experiment, known as R-103, discovered the production of neutral pions at high transverse momentum with a yield several orders of magnitude larger than expected. The result was again interpreted in terms of hard collisions between point-like proton constituents, demonstrating that these constituents also feel the strong interaction. "I had the privilege of working with Leon at Columbia in 1969–1970, when the R-103 experiment was proposed, and during the first years of ISR operation when he came to CERN," says Luigi Di Lella of CERN. "I remember Leon as a physicist with enormous imagination, a boundless source of stimulating and often unconventional new ideas, which he always presented in a friendly and joyful atmosphere."

As leader of the E70 and E288 experiments at Fermilab in the 1970s, Lederman also drove the effort that led to the discovery of the upsilon, the bound state of a bottom quark and antiquark, in 1977 (*CERN Courier* June 2017 p35). But his influence on the field of particle physics permeates far beyond his specific areas of research. In particular, he was a passionate advocate of education and worked with government and schools to create opportunities for students and better integrate physics into public education. He also had the rare quality to not take himself too seriously. Concerning the Higgs boson, he famously coined the term "God Particle" by using it in the title of his 1993 popular-science book *The God Particle: If the Universe Is the Answer, What Is the Question?* – though legend has it that he had originally wanted to call it the "God-dammed particle" because the Higgs boson was so difficult to find.

Lederman was director of the Nevis Laboratories at Columbia from 1961 to 1978. In 1979 he became director of Fermilab, where his vision and strategic planning led to the construction of the Tevatron (which operated from 1987 to 2011 and was the world's highest-energy accelerator before the Large Hadron Collider came along). He stepped down as Fermilab director in 1989 and joined the faculty of the University of Chicago and, later, the Illinois Institute of Technology.

"Leon Lederman provided the scientific vision that allowed Fermilab to remain on the cutting edge of technology for more than 40 years," says Nigel Lockyer, Fermilab's current director. "Leon's leadership helped to shape the field of particle physics, designing, building and operating the Tevatron and positioning the laboratory to become a world leader in accelerator and neutrino science. Leon had an immeasurable impact on the evolution of our laboratory and our commitment to future generations of scientists, and his legacy will live on in our daily work and our outreach efforts."

● *His friends and colleagues at CERN, with additional input from Fermilab.*

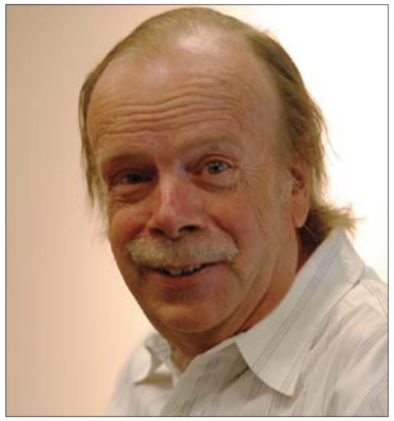
Paul Kunz 1942–2018

Paul Kunz, who revolutionised particle-physics computing and established the first Web server in the US, passed away on 12 September.

After completing a PhD in physics at Princeton University, Kunz began his illustrious 35 year-long career at the Stanford Linear Accelerator Center (SLAC) in 1974 as a research associate in David Leith's experimental physics Group B. As well as being an accomplished particle physicist, he quickly took an interest in one of the computing challenges facing experiments at the time – how to increase offline data-processing capability at a reasonable cost.

Using his deep understanding of computer architecture, software and hardware, he proposed a novel solution well beyond the norms of the time: the construction of a "farm" of interconnected processors each capable of executing IBM 370/168 instructions generated from standard FORTRAN code by an intermediate translator. In effect, the collection of interconnected computers in the farm would emulate, at a much lower cost, a single mainframe, distributing tasks to the individual processors, which became known as emulators. Each emulator would process entire events from particle interactions. Thus a simple parallel processing algorithm that did not require special programming or intricate modification to an experiment's existing software was born.

After forming a small team at SLAC and building a prototype emulator known as the 168/E, Paul met CERN computer specialists David Lord and Adolfo Fucci. They immediately expressed a desire to join forces. In fact, they were looking for an online filter processor that would execute standard offline FORTRAN code to make a selection of events for fast analysis by CERN's UA1 experiment,



SLAC

Paul Kunz established the first Web server in the US.

the so-called express line. Exhibiting his usual selfless interest in sharing ideas, Paul agreed to join forces, thereby establishing one of the first "real time" intercontinental collaborations by using the European Academic Research Network (EARN) and BITNET, courtesy of IBM.

The CERN/SLAC collaboration successfully constructed offline processing farms, notably for UA1. In parallel, one of the members of Paul's original team, Hanoch Brafman, went on to build a complementary 370/E emulator at the Weizmann Institute of Science in Israel. Subsequently, the CERN/SLAC teams developed the next-generation emulator, the 3081/E, which was used by UA1 and the Large Electron–Positron Collider (LEP) experiments in online and offline environments. The farms were inherently extendable by simply adding processors, and are arguably the inspiration for today's distributed offline computing facilities.

The success of the emulator-based UA1 third-level trigger facility pioneered the use of a processor farm for the so-called high-level trigger system, which has since been employed by most collider experiments (at LEP, the Tevatron and the LHC), albeit with commercial processors.

In the 1990s, Paul turned his attention to the challenges of software development and became a guru and advocator of object-oriented programming. He was a passionate user of Steve Job's NeXT computer and on an historic visit to CERN where he had regularly been giving courses on C++ programming, Paul immediately recognised the potential of the Web as demonstrated by Tim Berners-Lee and Robert Cailliau. Returning to SLAC, Paul not only installed the software on his NeXT, thereby establishing the first Web server in the US, he also connected it to the SPIRES database, giving the Web development team a "killer app", which demonstrated the huge potential of their project.

In his personal life, Paul was a champion BMW autocross driver and president of the Bay Area BMW club, at which he was also, along with his wife, a driving instructor for teenagers. When travelling to CERN, he would often land in Frankfurt, hire a BMW, and take it for a spin round the Nuremberg ring. He loved Chinese food and liked nothing better than to enjoy dinner in one of the many Chinese restaurants in the SLAC area with visiting friends and colleagues, often speaking French with his unique accent, a legacy of time spent at CEA Saclay in the 1970s.

Paul Kunz was a computing visionary and pioneer, and a great communicator who loved to share his ideas with irrepressible energy.

Thank you for all the bytes and bites, Paul.

● *Mick Storr, Adolfo Fucci and Paris Sphicas, assisted by other friends and colleagues of Paul.*

Karlheinz Meier 1955–2018

Karlheinz Meier, a visionary experimental particle physicist and co-founder of the Human Brain Project, unexpectedly passed away on 24 October, much too early, at the age of 63.

Karlheinz's career began at the University of Hamburg in Germany, where he studied physics. He completed his PhD there in 1984, with Gus Weber and Wulfrin Bartel as his supervisors, working for the JADE experiment at the PETRA electron–positron collider at DESY. During the following six years, he worked at CERN for the UA2 project, for two years as a CERN fellow and then as staff scientist. Returning to DESY in 1990, he joined the H1 collaboration. In 1992 he accepted a full professorship at Heidelberg University, where in 1994 he founded the Heidelberg ASIC Laboratory for Microelectronics and later, in 1999, the Kirchhoff Institute for Physics; during this period he also joined the ATLAS collaboration at CERN's Large Hadron Collider (LHC). He was vice-rector at Heidelberg University from 2001 to 2004, chair of the European Committee for Future Accelerators (ECFA) from 2007 to 2009, and a member of the governing board of the German Physical Society (DPG) from 2009 to 2013. Within the Human Brain Project – a major 10 year-long effort harnessing cutting-edge research infrastructure for the benefit of neuroscience, computing and brain-related medicine – he initiated the European Institute for Neuromorphic Computing (EINC) at Heidelberg. Sadly, the completion of the facility cannot be witnessed by him anymore.

Karlheinz was an extremely enthusiastic, visionary and energetic scientist. He made fundamental contributions to the instrumentation and data analysis of large particle-physics experiments, especially concerning calorimeter systems. Early on, during his PhD, he developed advanced algorithms for identifying photons with

F Hentschel

Karlheinz Meier was co-founder of the Human Brain Project.

the lead-glass calorimeter of JADE, an essential ingredient for his analysis of the inclusive production of photons, pions and η-mesons in multi-hadronic final states, but also for many studies of hadronisation and jet production, which JADE became famous for. Later, at CERN's UA2 experiment, he participated in the first analyses of the newly discovered W and Z bosons.

Back at DESY, he was one of the advocates and initiators of the H1 scintillating fibre "spaghetti" calorimeter, which was decisive for precise measurements of the proton structure. In addition, his research group built another specialised backward calorimeter for H1, the VLQ; by analysing the VLQ data, he was able to refute the then theoretical predictions on special multi-gluon states, such as the odderon (*CERN Courier* April 2018 p9). Karlheinz recognised early on the need for developing highly integrated electronic circuits for experimental physics, and his group – together with colleagues from the Heidelberg ASIC Laboratory – developed the pre-processor system of the ATLAS level-1 calorimeter trigger, which played a pivotal role in the discovery of the Higgs boson.

Since 2001, Karlheinz became increasingly interested in fundamental questions related to the physics of complex systems and information processing, with a focus on the development of neuromorphic hardware for decoding the functioning of the brain. In contrast to normal, programme-oriented Turing machines, neuromorphic systems are extremely energy efficient, error tolerant and self-adaptive – just like the human brain. His research results received special international recognition through the Human Brain Project, which he initiated together with Henry Markram and Richard Frackowiak, and which was selected by the European Union in 2012 as one of two so-called Flagship Projects of European research funding.

Karlheinz was also exceptional in supervising and motivating young researchers. He was a highly gifted teacher, whose lectures and seminars were loved by his students. Through his renowned "Team-Anderthalb" 90-second movies on a wide variety of basic physics topics, he became known to the wider public; they are available, like many other of his lectures and talks, on YouTube.

Curiosity for the fundamental questions of physics and technological innovation were the two driving forces that accompanied Karlheinz throughout his research life. He not only contributed significantly to the expansion of our knowledge about nature, but also gave new impetus to technological development, especially in the field of microelectronics and computing. His commitment to both research and teaching was outstanding and special. His passion, humanity, humour, overall guidance and inspiration will be sorely missed and not forgotten.

● *Siggi Bethke, Eckhard Elsen and Hans-Christian Schultz-Coulon, for his colleagues and friends worldwide.*

Ferenc Niedermayer 1945–2018

Ferenc Niedermayer, who played a prominent role in the development of lattice quantum chromodynamics (QCD), died on 12 August, aged 73.

Ferenc was born on 6 March 1945 in Budapest, Hungary. After obtaining a master's degree from Leningrad State University in 1968, where he met his future wife Tamara, he received his PhD in 1971 from Eötvös University in Budapest. Following a three-month stay at CERN's theory division in 1979, he worked at the Joint Institute for Nuclear Research in Dubna in 1980–1985 and at the University of California in San Diego in 1985–1986. Since 1989, he was a member of the Institute for Theoretical Physics at the University of Bern. In addition, he was a regular long-term visitor at the Max Planck Institute in Munich and at Eötvös University.

Ferenc was famous for possessing ▷

Faces & Places

an extraordinarily broad knowledge of physics. During the early stages of his career, he worked on a variety of phenomenological topics, ranging from polarised lepton–hadron scattering to J/ψ production in hadron–nucleus collisions and to neutrino oscillations. When he came to Bern, Ferenc began to work in a more theoretical direction, particularly on the novel discipline of lattice field theory – the study of lattice discretisations of quantum field theories such as QCD. Over the years, he obtained numerous results of lasting value in this and related fields, some of them in collaboration with his old friends János Balog, Péter Hasenfratz and Peter Weisz.

One famous result, which he obtained in collaboration with Hasenfratz and Michele Maggiore and made use of the intricate Wiener–Hopf technique, was the derivation of the mass gap of the two-dimensional O(3) model from its conjectured exact S-matrix. This model is often used as a prototypical solvable theory displaying many QCD-like features. Another celebrated result, which he achieved in collaboration with Hasenfratz and Victor Laliena and made use of the famous Ginsparg–Wilson relation, was the rigorous establishment of the Atiyah–Singer index theorem in a fully non-perturbative framework. This theorem plays a key role in the understanding of the vacuum structure and chiral symmetry properties of QCD.

R Bestgen

Ferenc Niedermayer played a key role in the development of lattice QCD.

After his retirement in 2010, Ferenc continued to work vigorously, both with new generations of students at Bern but in particular in a fruitful collaboration with Peter Weisz. This work continued and even accelerated after he received a diagnosis of liver cancer a few years ago. Ferenc talked openly about his illness. He always had a wonderful attitude towards work and life in general, and it was very inspiring to see how efficiently he spent his time.

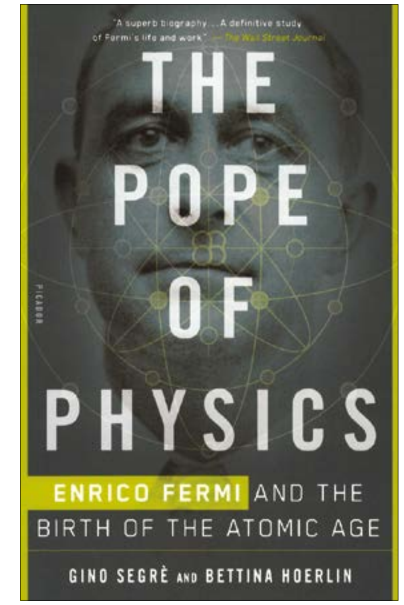
Towards the end of his life, Ferenc visited Hungary to bid farewell to many old friends and colleagues. He died peacefully a few days after returning to Bern. Many of his friends and colleagues, both from Switzerland and Hungary, honoured a great scientist and a wonderful man at his funeral.

● *His friends and colleagues.*

Bookshelf

COMPILED BY VIRGINIA GRECO, CERN

The Pope of Physics: Enrico Fermi and the Birth of the Atomic Age
By Gino Segrè and Bettina Hoerlin
Henry Holton and Co.



Enrico Fermi can be considered as one of the greatest physicists of all time due to his genius creativity in both theoretical and experimental physics. This book describes his prodigious story, as a man and a scientist.

Born in Rome in 1901, Fermi spent the first part of his life in Italy, where he made his brilliant debut in theoretical physics in 1926 by applying statistical mechanics to atomic physics in a quantum framework, thus sealing the birth of what is now known as Fermi–Dirac statistics. In 1933 he postulated the original theory of weak interactions to explain the mysterious results on nuclear ß decays. Having soon become a theoretical "superstar", he then switched to experimental nuclear physics, leading a celebrated team of young physicists at the University of Rome, known as the "boys". Among them were Edoardo Amaldi, Ettore Majorana, Bruno Pontecorvo, Franco Rasetti and Emilio Segrè. They nicknamed him "the Pope" since he knew and understood everything and was considered to be simply infallible. His discoveries on neutron-induced radioactivity and on the neutron slowing-down effect earned him the Nobel Prize in Physics in 1938.

Those were, however, difficult years for Fermi because of Italy's inconsistent research strategy and harsh political situation of fascism and antisemitism. Fermi left with his family to go to the US in December 1938, using the Nobel ceremony as a chance to travel abroad. Initially at Columbia University, Fermi then moved to the "Met Lab" of the University of Chicago, which was the seed of the Manhattan Project. There, he created the first self-sustained nuclear reactor in December 1942. The breakthrough ushered in the nuclear age, leaving a lasting impact on physics, engineering, medicine and energy – not to mention the development of nuclear weapons. In 1944 Fermi moved to the Manhattan Project's secret laboratory in Los Alamos. Within this project, he collaborated with some of the world's top scientists, including Hans Bethe, Niels Bohr, Richard Feynman, John von Neumann, Isidor Rabi, Leo Szilard and Edward Teller. These were terrible times of war.

When the Second World War concluded, Fermi resumed his research activities with energy and enthusiasm. On the experimental front he focused on nuclear physics, particle accelerators and technology, and early computers. On the theoretical front he concentrated on the origin of extreme high-energy cosmic rays. He also campaigned on the peaceful use of nuclear physics. As in Rome, in Chicago he was also the master of a wonderful school of pupils, among whom were several Nobel laureates. Fermi sadly died prematurely in 1954.

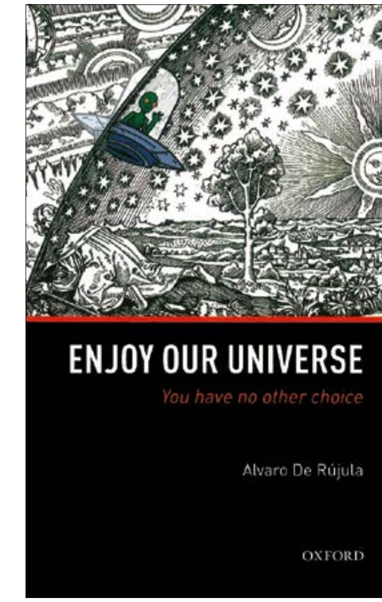
This book is about the epic life of Fermi, mostly known to the general public for the first ever nuclear reactor and the Manhattan Project, but to scientists for his theoretical and experimental discoveries – all diverse and crucial in modern physics – which always resulted in major advances. He remains less known as a personality or a public figure, and his scientific legacy is somehow underestimated. The merit of this book is therefore to bring Fermi's genius within everyone's reach.

Many renowned texts have been dedicated to Fermi until now, offering various perspectives on his life and his work. First of all on the personal life of Fermi, there is *Atoms in the Family* (1954) by his widow, Laura. Exhaustive information about Fermi's outstanding works in physics can be found in the volume *Enrico Fermi, Physicist* (1970) by his friend and colleague Emilio Segrè, Nobel laureate and Gino Segrè's uncle, and in *Enrico Fermi: Collected Papers*, two volumes published in the 1960s by the University of Chicago. Also worth mentioning are: *Fermi Remembered* (2004), edited by Nobel laureate James W Cronin; *Enrico Fermi: His Work and Legacy* (2001, then 2004), edited by C Bernardini and L Bonolis, and *The Lost Notebook of Enrico Fermi* by F Guerra and N Robotti (2015, then 2017), both published by the Italian Physical Society–Springer. Finally, published almost at the same time as Segrè and Hoerlin's book, is another biography of Fermi: *The Last Man Who Knew Everything* by D N Schwartz, the son of Nobel laureate Melvin Schwartz. In their "four-handed" book, Segrè and Hoerlin have highlighted with expertise the scientific biography of Fermi and his extraordinary achievements, and described with emotion the human, social and political aspects of his life.

Readers familiar with Fermi's story will enjoy this book, which is as scientifically sound as a textbook but at the same time bears the gripping character of a novel.

● *Luisa Cifarelli, Università di Bologna and Centro Fermi (Roma), Italy.*

Enjoy Our Universe, You Have No Other Choice
By Alvaro De Rújula
Oxford University Press



Scientific essays well suited to the interested layperson are notoriously difficult to write. It is then not surprising that various popular books, articles and internet sites recycle similar analogies – or even entire discussions – to explain scientific concepts with the same standardised, though very polished, language. CERN theorist Alvaro De Rújula recently challenged this unfortunate and relatively recent trend by proposing a truly original and unconventional essay for agile minds. There are no doubts that this book will be appreciated not only by the public but also by undergraduate students, teachers and active scientists.

Enjoy our Universe consists of 37 short chapters accounting for the serendipitous evolution of basic science in the last 150 years, roughly starting with the Faraday–Maxwell unification and concluding with the discovery of the Higgs boson and of gravitational waves. While going through the "fun" of our universe, the author describes the conceptual and empirical triumphs of classical and quantum field theories without indulging in excessive historic or technical details. Those who had the chance to attend lectures or talks given by De Rujula will recognise the "parentheses" (i.e. swift digressions) that he literally opens and closes in his presentations with gigantic brackets on the slides. A rather original glossary is included at the end of the text for the benefit of general readers.

This book is also a collection of opinions, reminiscences and healthy provocations of an active scientist whose contributions undeniably shaped the current paradigm of fundamental interactions. This is a bonus for practitioners of the field (and for curious colleagues), who will often find the essence of long-standing diatribes hidden in a collection of apparently innocent jokes or in the caption of a figure. As the author tries to argue in his introduction, science should always be discussed with that joyful and playful attitude we normally use when talking about sport and other interesting matters not immediately linked to the urgencies of daily life.

Science should always be discussed with a joyful and playful attitude.

One of the most interesting subliminal suggestions of this book is that physics is not a closed logical system. Basic science in general (and physics in particular) can only prosper if the confusion of ideas is tolerated and encouraged, at least within certain reasonable limits.

The text is illustrated with drawings by the author himself and this aspect, among others, brings to mind an imaginative popular essay by George Gamow (*Gravity* 1962), where the author drew his own illustrations (unfortunately not in colour) with a talent comparable to De Rújula's. The inspiration in this book is also a reminder of the autobiographical essay of Victor Weisskopf written almost 30 years ago, entitled *The Joy of Insight*, which echoes the enjoyment of the universe and suggests that the true motivation for basic science is the fun of curiosity: all the rest is irrelevant. So, please, enjoy our universe since you have no other choice!

● *Massimo Giovannini, CERN, and INFN Milan-Bicocca, Italy.*

Books received

Relativity in Modern Physics

By Nathalie Deruelle and Jean-Philippe Uzan
Oxford University Press

A century after its formulation by Einstein, the theory of general relativity is at the core of our interpretation of various astrophysical and cosmological observations – from neutron stars and black-hole formation to the accelerated expansion of the universe. This new advanced textbook on relativity aims to present all the different aspects of this brilliant theory and its applications. It brings together, in a coherent way, classical Newtonian physics, special relativity and general relativity, emphasising common underlying principles.

The book is structured in three parts around these topics. First, the authors provide a modern view of Newtonian theory, focusing on the aspects needed for understanding quantum and relativistic contemporary physics. This is followed by a discussion of special relativity, presenting relativistic dynamics in inertial and accelerated frames, and an overview of Maxwell's theory of electromagnetism.

In the third part the authors delve into general relativity, developing the geometrical framework in which Einstein's equations are formulated, and present many relevant applications, such as black holes, gravitational radiation and cosmology.

This book is aimed at undergraduate and graduate students, as well as researchers wishing to acquire a deeper understanding of relativity. But it could also appeal to the curious reader with a scientific background who is interested in discovering the profound implications of relativity and its applications.

Hadrons at Finite Temperature

By Samirnath Mallik and Sourav Sarkar
Cambridge University Press

In high-energy physics laboratories, experiments use heavy-ion collisions to investigate the properties of matter at extremely high temperature and density, and to study the quark–gluon plasma. This monograph explains the ideas involved in the theoretical analysis of the data produced in such experiments. It comprises three parts, the first two of which are independent but lay the ground for the topics addressed later.

The book starts with an overview of the (vacuum) theory of hadronic interactions at low energy: vacuum propagators for fields of different spins are introduced and then the phenomenon of spontaneous symmetry breaking leading to Goldstone bosons and chiral perturbation theory are discussed.

The second part covers equilibrium thermal field theory, which is formulated in the real time method. Finally, in the third part, the methods previously developed are applied to the study of different thermal one- and two-point functions in the hadronic phase, using chiral perturbation theory.

The book includes chosen exercises proposed at the end of each chapter and fully worked out. These are used to provide important side results or to develop calculations, without breaking the flow of the main text. Similarly, some of the results mentioned in the text are derived in a few appendices. It is a useful reference for graduate students interested in relativistic thermal field theory.

Recruitment

For advertising enquiries, contact *CERN Courier* recruitment/classified, IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK.
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.

FAIR

Facility for Antiproton and Ion Research

GSI

Helmholtzzentrum für Schwerionenforschung GmbH

GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt operates one of the leading particle accelerators for science. In the next few years, the new FAIR (**F**acility for **A**ntiproton and **I**on **R**esearch) one of the world's largest research projects, will be built in international cooperation. GSI and FAIR offer the opportunity to work together in this international environment with a team of employees committed to ensuring each day to conduct world-class science.

Within the department **„Accelerator Operations/Linac RF" (Linear Accelerator Radiofrequency)** we invite now qualified candidates to apply for the following position

Graduate Engineer or Master of Science (m/f)
Electrical Engineering / RF Technology or High Voltage Technology (TU/FH)
Ref. No. 6630-18.169

or comparable qualification.

Your tasks within the framework of the FAIR project and the operation as well as modernization of the existing high-frequency systems of GSI's heavy-ion linear accelerators are:

- Operation, maintenance and modernization of RF amplifier systems of up to 2 MW power (semiconductor and tube amplifier stages in pulse and continuous wave (cw) operation at 36 MHz up to 325 MHz) and the corresponding high voltage power supplies up to 24 kV as well as their sub-components for control and feedback control systems
- Support and further development of the interfaces between the RF components and the higher-level control and monitoring units of the accelerator systems
- System integration and documentation

Your qualification:

- Degree (Graduate or Master) in electrical engineering (or comparable)
- Knowledge in RF amplifier technology or high voltage technology
- Analogue and digital circuit development using common tools (Eagle, KiCAD, etc.)
- Good knowledge of German and English spoken and written
- Independently acting in smaller subprojects and readiness to work in new fields of activity

The ability to work in a team and a solution-oriented way of working are required. We offer a position with a high degree of self-reliance within the department of Linac RF.

We offer a permanent position. The salary is equivalent to that for public employees as specified in the collective agreement for public employees (TVöD Bund).

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

Handicapped persons will be preferentially considered when equally qualified.

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

If you find this position interesting and challenging and would like to work in an exceptional, international, strongly technical environment, please send your full application documents, including the desired salary, with information of your earliest possible starting date and the **reference number** above to the following address by **December, 28th, 2018** to

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

LIGO Laser Interferometer Gravitational-Wave Observatory
Supported by the National Science Foundation
Operated by Caltech and MIT

Postdoctoral Research Positions
LIGO Laboratory

The Laser Interferometer Gravitational-Wave Observatory (LIGO) has as its goal the development of gravitational wave physics and astronomy. The LIGO Laboratory is managed by Caltech and MIT, and is funded by the National Science Foundation. It operates observatory sites equipped with laser interferometric detectors at Hanford, Washington and Livingston, Louisiana, which recently made the first confirmed detection of gravitational waves. A vigorous LIGO Laboratory R&D program supports the development of enhancements to the LIGO detector as well as astrophysical data analysis, and development of future detectors and detector technologies.

The LIGO Laboratory anticipates having one or possibly more postdoctoral research positions at one or more of the LIGO sites – Caltech, MIT and at the two LIGO Observatories in Hanford, WA and Livingston, LA – beginning in Fall 2019. Hires will be made based on the availability of funding. Successful applicants will be involved in the operation of LIGO itself, analysis of LIGO data, both for diagnostic purposes and astrophysics searches, and/or the R&D program for future detector improvements. We seek candidates across a broad range of disciplines. Expertise related to astrophysics, modeling, data analysis, electronics, laser and quantum optics, vibration isolation and control systems is desirable. Most importantly, candidates should be broadly trained scientists, willing to learn new experimental and analytical techniques, and ready to share in the excitement of building, operating and observing with a gravitational-wave observatory. Appointments at the post-doctoral level will initially be for one-year with the possibility of renewal for up to two subsequent years.

Applications for postdoctoral research positions with LIGO Laboratory should indicate which of the LIGO sites (Caltech, MIT, Hanford, or Livingston), if any, are preferred by the applicant, and which (if any) are likely to be unworkable. Applications should be sent to HR@ligo.caltech.edu (Electronic Portable Document Format (PDF) submittals are preferred) and information provided is subject to the LIGO GDPR Policy – https://www.ligo.caltech.edu/page/gdpr-policy.

Caltech and MIT are Affirmative Action/Equal Opportunity employers. Women, minorities, veterans, and disabled persons are encouraged to apply.

Applications should include curriculum vitae, list of publications (with refereed articles noted), and the names, addresses, email addresses and telephone numbers of three or more references. Please attach a cover letter describing past experience and current and future research interests. Applicants should request that three or more letters of recommendations be sent directly to HR@ligo.caltech.edu (Electronic Portable Document Format (PDF) submittals are preferred). Consideration of applications will begin December 15, 2018 and will continue until all positions have been filled.

Caltech and MIT are Affirmative Action/Equal Opportunity Employers
Women, Minorities, Veterans, and Disabled Persons are encouraged to apply

More information about LIGO available at www.ligo.caltech.edu

The ELI (Extreme Light Infrastructure) Project is an integral part of the European plan to build the next generation of large research facilities. ELI-Beamlines as a cutting edge laser facility is currently being constructed near Prague, Czech Republic. ELI will be delivering ultra-short, ultra-intense laser pulses lasting typically a few tens of femtoseconds with peak power projected to reach 10 PW. It will make available time synchronized laser beams over a wide range of intensities for multi-disciplinary applications in physics, medicine, biology, material science etc. The high intensities of the laser pulse will be also used for generating secondary sources of e- and p+ and high-energy photons. Our research groups are expanding and recruiting physicists and engineers.

In our team we therefore have the following positions available:

- Junior Scientist
- Senior Scientist
- Laser Physicist
- Junior Engineer
- Senior Engineer
- Vacuum Technician
- Mechanical Designer
- Control System Specialist
- Safety Engineer
- Optical Engineer
- X-ray Scientist
- Opto-mechanics

For more information see our website www.eli-beams.eu and send your application, please.

eli beamlines

MINISTRY OF EDUCATION, YOUTH AND SPORTS

EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research, Development and Education

Inside Story

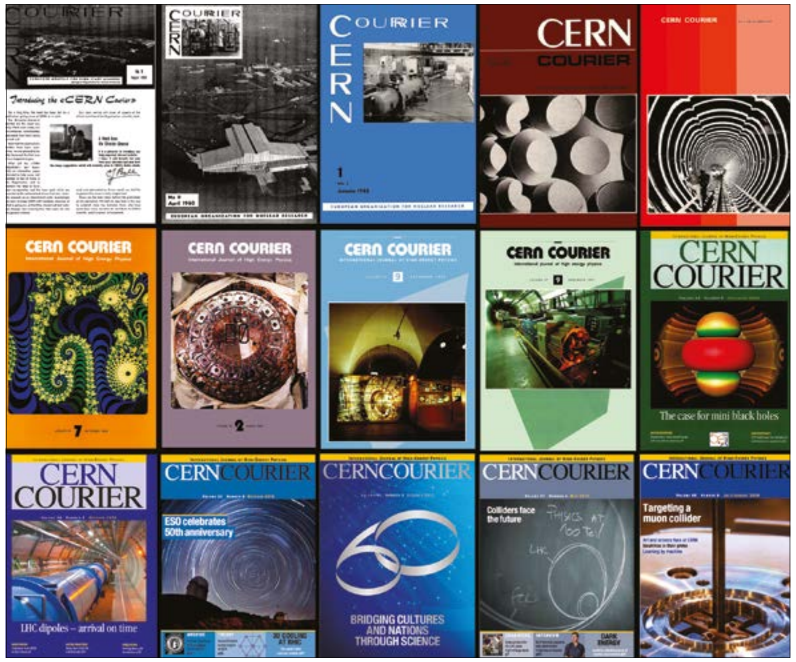
On the Courier's new future

"I think the *Courier* is excellent; it's sort of 'frozen in time', but in a rather appropriate and appealing way." Of all the lively comments received from the 1400 or so readers who took part in our recent survey (see page opposite), this one sums things up for the *CERN Courier*. "Excellent" might be a stretch for some, but, coming up for its 60th anniversary, this well-regarded periodical is certainly unique. It has been alongside high-energy physics as the field has grown up, from the rise of the Standard Model to the strengthening links with cosmology and astrophysics, the increasing scale and complexity of accelerators, detectors and computing, the move to international collaborations involving thousands of people, and other seismic shifts.

In terms of presentation, though, the *Courier* is indeed ripe for change. The website cerncourier.com was created in 1998 when the magazine's production and commercial dimensions were outsourced to IOP Publishing in the UK. Updated only 10 times per year with the publication of each print issue, the website has had a couple of makeovers (one in 2007 and one earlier this year) but its functionality remains essentially unchanged for 20 years.

A semi-static, print-led website is no longer best suited to today's publishing scene. The sheer flexibility of online publishing allows more efficient ways to communicate different stories to new audiences. Our survey concurs: a majority of readers (63%) indicated that they were willing to receive fewer print copies per year if cerncourier.com was updated more regularly – a view held most strongly among younger responders. It is this change to its online presence that drives the new publishing model of *CERN Courier* from 2019, with a new, dynamic website planned to launch in the spring.

At the same time, there is high value attached to a well-produced print magazine that worldwide readers can receive free of charge. And, as the results of our survey show, a large section of the community reads the *Courier* only when they pick up a copy in their labs or universities to browse over lunch or while travelling. That's why the print magazine is staying, though at a reduced frequency of six rather than 10 issues per year. To reflect this change, the magazine will have a new look from next year. Among many improvements, we have adopted a more readable font, a clearer layout and other modern design features. There are new and revised sections covering careers, opinion and reviews, while the feature articles – the most popular according to our survey – will remain as the backbone of the issue.



The *Courier* strives to be as enjoyable as it is authoritative.

It is sometimes said that the *Courier* can be a bit too formal, a little dry. Yet our survey did not reveal a huge demand to lighten things up – so don't expect to see Sudoku puzzles or photos of your favourite pet any time soon. That said, the *Courier* is a magazine, not an academic journal; in chronicling progress in global high-energy physics it strives to be as enjoyable as it is authoritative.

Another occasional criticism is that the *Courier* is a mere mouthpiece for CERN. If it is, then it is also – and unashamedly – a mouthpiece for other labs and for the field as a whole. Within just a few issues of its publication, the *Courier* outgrew its original editorial remit and expanded to cover activities at related laboratories worldwide (with the editorially distinct *CERN Bulletin* serving the internal CERN community). The new-look *Courier* will also retain an important sentence on its masthead demarcating the views stated in the magazine from those of CERN management.

A network of around 30 laboratory correspondents helps to keep the magazine updated with news from their facilities on an informal basis. But the more members of the global high-energy physics community who interact, the better the *Courier* can serve them. Whether it's a new result, experiment, machine or theorem, an event, appointment or prize, an opinion, review or brazen self-promotion, get in touch at cern.courier@cern.ch.

● *Matthew Chalmers, editor.*

Reader survey: the results are in

To shape the *Courier*'s new life in print and online, a survey was launched this summer in conjunction with IOP Publishing to find out what readers think of the magazine and website, and what changes could be made. The online survey asked 21 questions and responders were routed to different sections of the survey depending on the answers they provided. Following promotion on cerncourier.com, CERN's website, *CERN Bulletin*, social media channels and e-mails to CERN users, there were a total of 1417 responses.

Responders were split roughly 3:1 male to female, with a fairly even age distribution. Geographically, they were based predominantly in France, the US, Italy, Switzerland, Germany and the UK. Some 43% of the respondents work at a university, followed by a national or international research institute (34%), with the rest working in teaching (5%) and various industries. While three-quarters of the respondents named experimental particle physics as their main domain of work, many have other professional interests ranging from astronomy to marketing.

Responders were evenly split between those that read the printed magazine and those that don't. Readers tend to read the magazine on a regular basis and, overall, have been reading for a significant period of time. A majority (54.1%) do not read the magazine via a direct subscription, and the data suggest that one copy of the *Courier* is typically read by more than one person.

In terms of improving the *CERN Courier* website, there was demand for a mobile-optimised platform and for video content, though a number of respondents were unaware that the website even existed. Importantly for the future of *CERN Courier*, a majority of readers (63%) indicated that they were willing to receive fewer print copies per year if cerncourier.com was updated more regularly; this trend was sharpest in the under-30 age group.

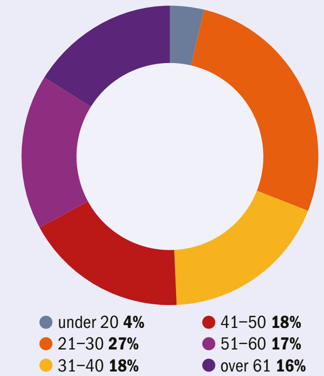
When it comes to the technical level of the articles, which is a topic of much consideration at the *Courier*, the responses indicate that the level is pitched just right (though, clearly, a number of readers will find some topics tougher than others given the range of subfields within high-energy physics). Readers also felt that their fields were well represented, and agreed that more articles about careers and people would be of interest.

Many written comments were provided, a few of which are listed here: "More investigative articles please"; "I would like that it has a little glossary"; "A column about people themselves, not only the physics they do"; "More debate on topics on which there is discussion in the field"; "Please do NOT modify *CERN Courier* into a 'posher' version"; "Leave out group photos of people at big meetings"; and "Make a *CERN Courier* kids edition". The overwhelming majority of comments were positive, and the few that weren't stood out: "The whole magazine reads like propaganda for CERN and for the Standard Model"; "The *Courier* style is intentionally humourless, frigid, stale and boring. Accordingly, almost everybody agrees that the obituaries are by far its best part"; and, curiously, "The actual format is so boring that I stop to read it!"

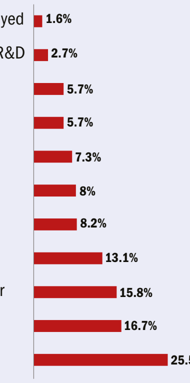
It only remains to thank participants of the survey and to congratulate the winners of our random prize draw (V Boudry, J Baeza, S Clawson, V Lardans and M Calvetti), who each receive a branded CERN hoodie.

● *Matthew Chalmers, CERN, and Laura Gillham, IOP Publishing.*

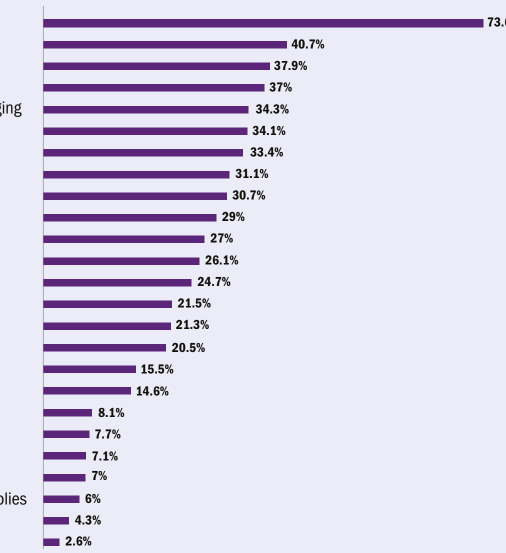
Age of survey responders



What is your professional position?



What are your professional interests?



CERNCOURIER
Volume 58 Number 10 December 2018
IOP Publishing

CERN Courier Archive: 1975

A look back to CERN Courier vol. 15, December 1975, compiled by Peggie Rimmer

CORNELL

Honouring Hans Bethe

Wide World Photo

Hans Bethe (left) taking a bike ride around the 12 GeV electron synchrotron at Cornell, with the Director of the Wilson Synchrotron Laboratory, Boyce McDaniel, at the dedication of the Laboratory in 1968.

Physicists and friends from all over the USA assembled at Cornell University on 24 October to honour Hans Bethe on his retirement.

Bethe has made important contributions to the fields of atomic, solid state and nuclear physics, and to the development of the theory of radiation. In 1967 he was awarded the Nobel Prize for calculations explaining how a star uses nuclear fuel as its power source, published in 1938. It is now known that most of the starlight visible in the night sky is produced by the 'Bethe cycle'.

In the past 20 years his research has been devoted largely to explaining the structure of nuclei in terms of the forces acting among their constituents. He has also been interested in neutron stars, thought to be made up of matter closely packed at nuclear densities. He is now working on problems of nuclear physics as the Karl Compton Professor of Physics at the Massachusetts Institute of Technology.

● Compiled from text on pp392–393.

FERMILAB

Lots of protons

Since its summer shutdown ended on 1 August, the synchrotron at the Fermi National Accelerator Laboratory has been operating mainly at an energy of 400 GeV. Previously it was best described as a 300 GeV machine making occasional excursions to 400 GeV. It is now running just as efficiently at the higher energy, averaging some 100 hours of physics out of the 125 hours scheduled each week.

The intensity at 400 GeV has reached 1.72×10^{13} protons per pulse (compared with 1.75×10^{13} at 300 GeV). Most effort is now going towards achieving higher beam intensities. The high energies and high intensities bring additional problems in their wake but they are all under reasonable control.

With these quantities of protons pouring out of the machine, experimenters can be kept happy in all three experimental areas at once – Meson, Neutrino and Proton.

The Fermilab building at night is a striking sight, Hi-Rising from the plains of Illinois. Inside, flora and fauna create a refreshing atmosphere. Fermilab Director, R R Wilson, drew much of his inspiration in selecting this layout from the restaurant–coffee lounge area in the CERN Main Building.

● Compiled from text on pp394–395.

CERN

The COURIER 1976

New methods of production and distribution of the COURIER will be operated from the beginning of 1976. They result from discussions during the past year to see how the journal can better serve the high energy physics community. The guiding idea has been that the usefulness of the COURIER will be increased if it becomes more fully representative of the community at a time when the social and political climate makes integration of the whole field of research even more desirable.

We hope that after a few months of 'running in', we shall establish a better flow of news so that we can convey stories of what is happening in and around the field of high energy physics, no matter where these stories emerge.

● Compiled from text on pp397–398.

CERN 214.11.75

On 13 November diplomats from the Chinese Mission in Geneva and Embassy in Berne were invited to visit CERN as a gesture of appreciation for their considerable help in organizing the visit of the CERN delegation to China in September. While their husbands busied themselves with things scientific and technical, the diplomats' wives relaxed for a while, visiting the CERN Nursery School.

● Compiled from text on p389.

Compiler's note

With "2019" replacing "1976" in the excerpt concerning *CERN Courier*, the contents could pass almost unedited given the changes planned from next year (see p56). Out with the old, in with the new – sort of.

This archive feature will continue, with its backwards glance to yesteryears, albeit in a different format. If it provides a wistful touch of nostalgia for readers who were there then, for the majority who have come later it shows just how much things have changed – or maybe just how little in some cases!