WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the March 2015 issue of *CERN Courier*.

To celebrate the International Year of Light and Light-based Technologies (IYL2015) this issue looks at how brilliant, accelerator-based X-ray free-electron lasers are enabling exciting new studies in biology. Moreover, as Lucio Rossi explains in Viewpoint, accelerators provide the finest form of "light" with their high-energy particle beams, and experiments can now "see" down to distances as small as 10^{-20} m. In this way, the High-Luminosity LHC project will allow CERN's collider to cast still more of this fine light on matter. Finally, Inside Story looks at how light and particle physics came together in the life of one physicist.

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

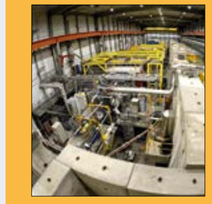
To subscribe to the magazine, the e-mail new-issue alert, please visit:
http://cerncourier.com/cws/how-to-subscribe.

EDITOR: CHRISTINE SUTTON, CERN
DIGITAL EDITION CREATED BY JESSE KARJALAINEN/IOP PUBLISHING, UK

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERNCOURIER

VOLUME 55 NUMBER 2 MARCH 2015



COMPASS
Precise new result aligns with QCD benchmark
p5

VIEWPOINT
Lucio Rossi on the finest kind of light
p54

SPIN2014 IN CHINA
From spin physics to spintronics **p33**

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 Christine Sutton
News editor Kate Kahle
CERN, 1211 Geneva 23, Switzerland
E-mail cern.courier@cern.ch
Fax +41 (0) 22 785 0247
Web cerncourier.com

Advisory board Luis Álvarez-Gaumé, James Gillies, Horst Wenninger

Laboratory correspondents:
Argonne National Laboratory (US) Tom LeCompte
Brookhaven National Laboratory (US) P Yamin
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) Katie Yurkewicz
Forschungszentrum Jülich (Germany) Markus Buescher
GSI Darmstadt (Germany) I Peter
IHEP, Beijing (China) Tongzhou Xu
IHEP, Serpukhov (Russia) Yu Ryabov
INFN (Italy) Romeo Bassoli
Jefferson Laboratory (US) Steven Corneliussen
JINR Dubna (Russia) B Starchenko
KEK National Laboratory (Japan) Saeko Okada
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) Julia Maddock
SLAC National Accelerator Laboratory (US) Farnaz Khadem
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 Lisa Gibson
Technical illustrator Alison Tovey
Group advertising manager Chris Thomas
Advertisement production Katie Graham
Marketing & Circulation Angela Gage

Head of B2B & Marketing Jo Allen
Art director Andrew Giaquinto

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

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 Keqing Ma, Library, Institute of High Energy Physics,
PO Box 918, Beijing 100049, People's Republic of China
E-mail: keqingma@mail.ihep.ac.cn
Germany Antje Brandes, DESY, Notkestr. 85, 22607 Hamburg, Germany
E-mail: desypr@desy.de
Italy Loredana Rum or Anna Pennacchietti, INFN, Casella Postale 56, 00044 Frascati, Rome, Italy
E-mail: loredana.rum@lnf.infn.it
UK Mark Wells, Science and Technology Facilities Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1SZ
E-mail: mark.wells@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 55 NUMBER 2 MARCH 2015

On the cover: This year is the International Year of Light, which CERN is celebrating in the context of the High-Luminosity LHC project (p28), which will cast more "finest light" on the structure of matter (p54). (Image credit: CERN.)

News

QCD PHYSICS

COMPASS measures the pion polarizability

The COMPASS experiment at CERN has made the first precise measurement of the polarizability of the pion – the lightest composite particle built from quarks. The result confirms the expectation from the low-energy expansion of QCD – the quantum field theory of the strong interaction between quarks – but is at variance with the previously published values, which overestimated the pion polarizability by more than a factor of two.

Every composite system made from charged particles can be polarized by an external electromagnetic field, which acts to separate positive and negative charges. The size of this charge separation – the induced dipole moment – is related to the external field by the polarizability. As a measure of the response of a complex system to an external force, polarizability is directly related to the system's stiffness against deformability, and hence the binding force between the constituents.

The pion, made up of a quark and an antiquark, is the lightest object bound by the strong force and has a size of about 0.6×10^{-15} m (0.6 fm). So to observe a measurable effect, the particle must be subjected to electric fields in the order of 100 kV across its diameter – that is, about 10^{18} V/cm. To achieve this, the COMPASS experiment made use of the electric field around nuclei. To high-energy pions, this field appears as a source of (almost) real photons, on which the incident pions scatter.

The COMPASS experiment in the North Area on the Prévessin site at CERN studies hadron structure both with pion beams and with muon beams – a powerful combination. (Image credit: CERN-EX-1105182-01.)

Such pion–photon Compton scattering, also known as the Primakoff mechanism, was explored in the early 1980s in an experiment at Serpukhov, but the small data sample led to only an imprecise value for the polarizability of 6.8 ± 1.4 (stat.) ±1.2 (syst.) $\times10^{-4}$ fm^3, where the systematic uncertainty was underestimated, presumably.

COMPASS has now achieved a modern Primakoff experiment, using a 190 GeV pion beam from the Super Proton Synchrotron at CERN directed at a nickel target. Importantly, COMPASS was also able to use muons, which are point-like and hence non-deformable, to calibrate the experiment. The Compton $\pi\gamma\rightarrow\pi\gamma$ scattering is extracted from the reaction $\pi^-\text{Ni}\rightarrow\pi^-\gamma\text{Ni}$ by selecting events from the Coulomb peak at small momentum transfer. From the analysis of a sample of 63,000 events, the collaboration obtained a value of the pion electric polarizability of 2.0 ± 0.6 (stat.) ±0.7 (syst.) $\times10^{-4}$ fm^3 – that is, about 2×10^{-4} of the pion's volume. This value is in good agreement with theoretical calculations in low-energy QCD, therefore solving a long-standing discrepancy between these calculations and previous experimental efforts to determine the polarizability.

Although this measurement is the first to allow a self-calibration, the accuracy is still below the quoted uncertainty of the calculations. With more data already recorded, the COMPASS collaboration expects to improve on this result by a significant factor in the near future, and thereby probe further a benchmark calculation of non-perturbative QCD.

● Further reading

COMPASS Collaboration 2015 arXiv:1405.6377 [hep-ex], to be published in *Phys. Rev. Lett.*

The International Year of Light

INTERNATIONAL YEAR OF LIGHT 2015

On 20 December 2013, the UN General Assembly proclaimed 2015 as the International Year of Light and Light-based Technologies (IYL 2015). The aim is to raise awareness about how these technologies provide solutions to global challenges in energy, education, agriculture and health.

In its quest to "see" the fundamental structure of matter, high-energy particle physics goes beyond the wavelengths of light to the wavelengths of particle beams. Over the years, developments in the accelerators that create those beams have led to new ways of producing light that have a big impact on other disciplines.

To celebrate the IYL 2015, this issue of *CERN Courier* looks at how brilliant, accelerator-based X-ray free-electron lasers are enabling exciting new studies in biology (p19). Meanwhile, as Lucio Rossi points out in Viewpoint, accelerators provide the finest form of "light", and experiments can now "see" down to distances as small as 10^{-20} m (p54). The High-Luminosity LHC project (p28) will allow CERN's collider to cast still more of this fine light on matter. Finally, Inside Story (p53) looks at how light and particle physics came together in the life of one physicist.

Sommaire en français

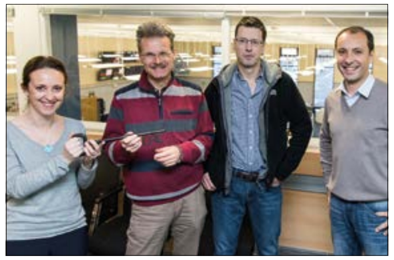
LHC NEWS

Holding the key to LHC Run 2

On 12 January, after 23 months of hard work involving around 1000 people each day, the key to the LHC was symbolically handed back to the operations team. The team will now perform tests on the machine in preparation for the restart this spring.

Tests include training the LHC's superconducting dipole magnets to the current level needed for 6.5 TeV beam energy. The main dipole circuit of a given sector is ramped up until a quench of a single dipole occurs. The quench-protection system then swings into action, energy is extracted from the circuit, and the current is ramped down. After careful analysis, the exercise is repeated. On the next ramp, the magnet that quenched should hold the current (i.e. is trained), while at a higher current another of the 154 dipoles in the circuit quenches. For 2015, the target current is 11,080 A for operation at 6.5 TeV (with some margin). Sector 6-7 was brought to this level successfully at the end of 2014, having taken 20 training quenches to get there. Getting all eight sectors to this level will be an important milestone.

The next big step is the first sector test, in which beam would enter the LHC for the first time since February 2013. The aim is to send single bunches from the Super Proton Synchrotron into the LHC through the injection regions at points 2 and 8 for a single pass through the available downstream sectors. This will allow testing of synchronization, the injection system, beam instrumentation, magnet settings, machine aperture and the beam dump.



LS1 activities co-ordinator Katy Foraz symbolically hands the LHC key to the operations team, represented, left to right, by Jorg Wenninger, Mike Lamont and Mirko Pojer. (Image credit: CERN-PHOTO-201501-002 – 3.)

A full circuit of the machine with beam and the start of beam commissioning are foreseen for March. It should then take about two months to re-commission the operational cycle, commission the beam-based systems (transverse feedback, RF, injection, beam dump system, beam instrumentation, power converters, orbit and tune feedbacks, etc) and commission and test the machine-protection system to re-establish the high level of protection required. This will open the way for the first collisions of stable beams at 6.5 TeV – foreseen currently for May – initially with a low number of bunches.

On 26 January, the CMS collaboration installed their new Pixel Luminosity Telescope (PLT). Designed with LHC Run 2 in mind, the PLT uses radiation-hard CMS pixel sensors to provide near-instantaneous readings of the per-bunch luminosity – thereby helping LHC operators to provide the maximum useful luminosity to CMS. The PLT is comprised of two arrays of eight small-angle telescopes situated on either side of the CMS interaction point. Each telescope hovers only 1 cm away from the CMS beam pipe, where it uses three planes of pixel sensors to take separate, unique measurements of luminosity. (Image credit: CERN-PHOTO-201501-014 – 10.)

ASTROPARTICLE PHYSICS

Detection techniques for future neutrino observatories

The discovery of high-energy astrophysical neutrinos initially announced by IceCube in 2013 provided an added boost to the planning for new, larger facilities that could study the signal in detail and identify its origins. Three large projects – KM3NeT in the Mediterranean Sea, IceCube-Gen2 at the South Pole and the Gigaton Volume Detector (GVD) in Lake Baikal – are already working together in the framework of the Global Neutrino Network (*CERN Courier* December 2014 p11).

In December, the RWTH Aachen University hosted a workshop on these projects and their low-energy sub-detectors, ORCA and PINGU, which aim at determination of the neutrino-mass hierarchy through precision measurements of atmospheric-neutrino oscillations. Some 80 participants from 11 different countries came to discuss visionary strategies for detector optimization and technological aspects common to the high-energy neutrino telescopes.

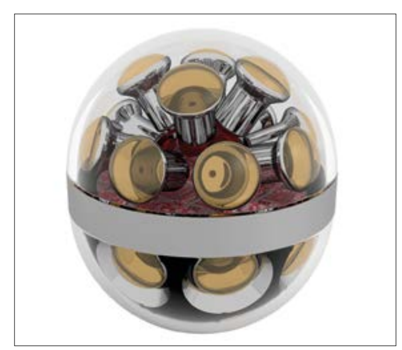
Photodetection techniques, as well as trigger and readout strategies, formed one particular focus. All of the detectors are based on optical modules consisting of photomultiplier tubes (PMTs) housed in a pressure-resistant glass vessel together with their digitization and read-out electronics. Representatives of the experiments shared their experiences on the development, *in situ* performance and mass-production of the different designs. While the baseline design for IceCube-Gen2 follows the proven IceCube modules closely, KM3NeT has successfully deployed and operated prototypes of a new design consisting of 31 3" PMTs housed in a single glass sphere, which offer superior timing and intrinsic directional information. Adaption of this technology for IceCube is under investigation.

New and innovative designs for optical modules were also reviewed, for example a large-area sensor employing wavelength-shifting and light-guiding techniques to collect photons in the blue and UV range and guide them to a small-diameter low-noise PMT. Presentations from Hamamatsu Photonics and Nautilus Marine Service on the latest developments in photosensors and glass housings, respectively, complemented the other talks nicely.

In addition, discussions centred on auxiliary science projects that can be carried out at the planned infrastructures. These can serve as a test bed for completely new detection technologies, such as acoustic neutrino detection, which is possible in water and ice, or radio neutrino detection, which is limited to ice as the target medium. Furthermore, IceCube-Gen2 at the South Pole offers the unique possibility to install detectors on the surface above the telescope deep in the ice, the latter acting as a detector for high-energy muons from cosmic-ray-induced extensive air showers. Indeed, the interest in cosmic-ray detectors on top of an extended IceCube telescope reaches beyond the communities of the three big projects.

The second focus of the workshop addressed the physics potential of cosmic-ray detection on the multi-kilometre scale, and especially the use of a surface array as an air-shower veto for the detection of astrophysical neutrinos from the southern sky at the South Pole. The rationale for surface veto techniques is the fact that the main background to extraterrestrial neutrinos from the upper hemisphere consists of muons and neutrinos produced in the Earth's atmosphere. These particles are correlated to extended air showers, which can be tagged by a surface array. While upward-moving neutrinos have to traverse the entire Earth and are absorbed above some 100 TeV energy, downward-moving neutrinos do not suffer from absorption. Therefore a surface veto is especially powerful for catching larger numbers of cosmic neutrinos at the very highest energies.

The capabilities of these surface extensions together with deep-ice components will be evaluated in the near future. Presentations at the workshop on various detection techniques – such as charged-particle detectors, imaging air-Cherenkov telescopes and Cherenkov timing arrays – allowed detailed comparisons of their capabilities. Parameters of interest are duty cycle, energy threshold and the cost for construction and installation. The development of different detectors for applications in harsh environments is already on its way and the first prototypes are scheduled to be tested in 2015.



Concept for an IceCube-Gen2 multi-PMT digital optical module (OM), motivated by the OM from KM3NeT. (Image credit: Alexander Kappes.)

● The Detector Design and Technology for Next Generation Neutrino Observatories workshop was supported by the Helmholtz Alliance for Astroparticle Physics (HAP), RWTH Aachen University, and Hamamatsu Photonics. For more information, visit hap2014.physik.rwth-aachen.de.

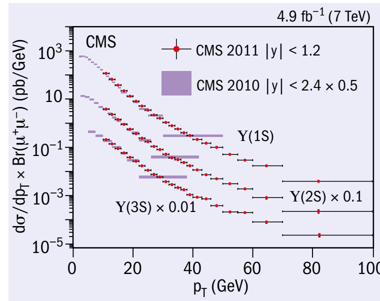
LHC EXPERIMENTS

CMS heads towards solving a decades-long quarkonium puzzle

Quarkonia – charm or beauty quark/antiquark bound states – are prototypes of elementary systems governed by the strong force. Owing to the large masses and small velocities of the quarks, their mutual interaction becomes simpler to describe, therefore opening unique insights into the mechanism of strong interactions. For decades, research in the area of quarkonium production in hadron collisions has been hampered by anomalies and puzzles in theoretical calculations and experimental results (*CERN Courier* July/August 2013 p30), so that, until recently, the studies were stuck at a validation phase. Now, new CMS data are enabling a breakthrough by accomplishing cross-section measurements for quarkonium production that reach unprecedentedly high values of transverse momentum (p_T).

The latest and most persistent "quarkonium puzzle", lasting for more than 10 years, was the seeming impossibility of theory to reproduce simultaneously quarkonium yields and polarizations, as observed in hadronic interactions. Polarization is particularly sensitive to the mechanism of quark–antiquark ($q\bar{q}$) bound-state formation, because it reveals the quantum properties of the pre-resonance $q\bar{q}$ pair. For example, if a $^3S_1$ bound state (J/ψ or ϒ) is measured to be unpolarized (isotropic decay distribution), the straightforward interpretation is that it evolved from an initial coloured $^1S_0$ $q\bar{q}$ configuration. To extract this information from differential cross-section measurements requires an additional layer of interpretation, based on perturbative calculations of the pre-resonance $q\bar{q}$ kinematics in the laboratory reference frame. The fragility of this additional step will reveal itself, *a posteriori*, as *the* cause of the puzzle.

In recent years, CMS provided the first unambiguous evidence that the decays of $^3S_1$ bottomonia (ϒ(1,2,3S)) and charmonia (J/ψ, ψ(2S)) are always approximately isotropic (CMS Collaboration 2013): the pre-resonance $q\bar{q}$ is a $^1S_0$ state neutralizing its colour into the final $^3S_1$ bound state. This contradicted the idea that quarkonium states are produced mainly from a transversely polarized gluon (coloured $^3S_1$ pre-resonance), as deduced traditionally from cross-section measurements. After having exposed the



The latest ϒ(nS) → µµ differential p_T cross-sections (CMS Collaboration 2014) compared with the previous result (CMS Collaboration 2013) shown as cross-hatched areas.

polarization problem with high-precision measurements, CMS is now providing the key to its clarification.

The new cross-section measurements allow a theory/data comparison at large values of the ratio p_T/mass, where perturbative calculations are more reliable. First attempts to do so, not yet exploiting the exceptional high-p_T reach of the newest data, were revealing. With theory calculations restricted to their region of validity, the cross-section measurements are actually found to agree with the polarization data, indicating that the bound-state formation through coloured $^1S_0$ pre-resonance is dominant (G Bodwin *et al*. 2014, K-T Chao *et al*. 2012, P Faccioli *et al*. 2014).

Heading towards the solution of a decades-long puzzle, what of the fundamental question: how do quarks and antiquarks interact to form bound states? Future analyses will disclose the complete hierarchy of transitions from pre-resonances with different quantum properties to the family of observed bound states, providing a set of "Kepler" laws for the long-distance interactions between quark and antiquark.

● Further reading

G Bodwin *et al.* 2014 *Phys. Rev. Lett.* **113** 022001.
K-T Chao *et al.* 2012 *Phys. Rev. Lett.* **108** 242004.
CMS Collaboration 2014 CMS-PAS-BPH-12-006; CMS-PAS-BPH-14-001; CERN-PH-EP-2015-007.
CMS Collaboration 2013 *Phys. Rev. Lett.* **110** 081802; *Phys. Lett. B* **727** 381.
P Faccioli *et al.* 2014 *Phys. Lett. B* **736** 98.

CERN Courier March 2015

News

ALICE sheds light on particle production in heavy-ion collisions

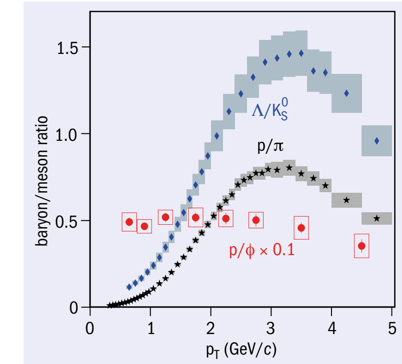
New results from the ALICE collaboration are providing additional data to test ideas about how particles are produced out of the quark–gluon plasma (QGP) created in heavy-ion collisions at the LHC.

Experiments at Brookhaven's Relativistic Heavy Ion Collider (RHIC) observed an enhancement in p_T-dependent baryon/meson ratios – specifically the p/π and Λ/K^0_S ratios – for central nucleus–nucleus (AA) collisions in comparison with proton–proton (pp) collisions, where particle production is assumed to be dominated by parton fragmentation. In addition, constituent-quark scaling was observed in the elliptic-flow parameter, v_2, measured in AA collisions. To interpret these observations, the coalescence of quarks was suggested as an additional particle-production mechanism. The coalescence (or recombination) model postulates that three quarks must come together to form a baryon, while a quark and an antiquark must coalesce to form a meson. The p_T and the v_2 of the particle created is the sum of the respective values of the constituent quarks. Therefore, coalescence models generally predict differences between the p_T spectra of baryons and mesons, predominantly in the range $2 < p_T < 5$ GeV/c, where the enhancement in the baryon/meson ratio has been measured.

While a similar enhancement in the p/π and Λ/K^0_S ratios is observed at the LHC, the mass scaling of v_2 is not, calling into question the importance of the coalescence mechanism. The observed-particle p_T spectra reflect the dynamics of the expanding QGP created in local thermal equilibrium, conferring to the final-state particles a common radial velocity independent of their mass, but a different momentum (hydrodynamic flow). The resulting blue shift in the p_T spectrum therefore scales with particle mass, and is observed as a rise in the p/π and Λ/K^0_S ratios at low p_T (see figure). In such a hydrodynamic description, particles with the same mass have p_T spectra with similar shapes, independent of their quark content. The particular shape of the baryon/meson ratio observed in AA collisions therefore reflects the relative importance of hydrodynamic flow, parton fragmentation and quark coalescence. However, for the p/π and Λ/K^0_S ratios, the particles in the numerator and denominator differ in both mass and (anti)quark content, so coalescence and hydrodynamic effects cannot be disentangled. To test the role of coalescence further, it is instructive to conduct this study using a baryon and a meson that have similar mass.

Fortunately, nature provides two such particles: the proton, a baryon with mass 938 MeV/c^2, and the ϕ meson, which has a mass of 1019 MeV/c^2. If protons and ϕ mesons are produced predominantly through coalescence, their p_T spectra will have different shapes. Hydrodynamic models alone would predict p_T spectra with similar shapes owing to the small mass-difference (less than 9%), implying a p/ϕ ratio that is constant with p_T.

For peripheral lead–lead collisions, where the small volume of the quark–gluon plasma reduces the influence of collective hydrodynamic motion on the p_T spectra, the p/ϕ ratio has a strong dependence on p_T, similar to that observed for pp collisions.



The flat dependence on p_T of the p/ϕ ratio measured by ALICE for central lead–lead collisions, compared with the p/π and Λ/K^0_S ratios, indicates hydrodynamics as the leading contribution to the p_T spectra.

In contrast, as the figure shows, in central lead–lead collisions – where the volume of the QGP produced is largest – the p/ϕ ratio has a very different p_T dependence, and is constant within its uncertainties for $p_T < 4$ GeV/c. The data therefore indicate that hydrodynamics is the leading contribution to particle p_T spectra in central lead–lead collisions at LHC energies, and it does not seem necessary to invoke coalescence models.

In the coming year, the ALICE collaboration will measure a larger number of collisions at a higher energy. This will allow a more precise study of both the p_T spectra and elliptic-flow parameters of the proton and ϕ meson, and will allow tighter constraints to be placed on theoretical models of particle production in heavy-ion collisions.

● Further reading

B Abelev *et al.* ALICE Collaboration 2014 arXiv:1404.0495 [nucl-ex], accepted for publication in *Phys. Rev. C*.

ATLAS gives new limits in the search for dark matter

There is evidence for dark matter from many astronomical observations, yet so far, dark matter has not been seen in particle-physics experiments, and there is no evidence for non-gravitational interactions between dark matter and Standard Model particles. If such interactions exist, dark-matter particles could be produced in proton–proton collisions at the LHC. The dark matter would travel unseen through the ATLAS detector, but often one or more Standard Model particles would accompany it, either produced by the dark-matter interaction or radiated from the colliding partons. Observed particles with a large imbalance of momentum in the transverse plane of the detector could therefore signal the production of dark matter.

Because radiation from the colliding partons is most likely a jet, the "monojet" search is a powerful search for dark matter. The ATLAS collaboration now has a new result in this channel and, while it does not show evidence for dark-matter production at the LHC, it does set significantly improved limits on the possible rate for a variety of interactions. The reach of this analysis depends strongly on a precise determination of the background from Z bosons decaying to neutrinos at large-boson transverse-momentum. By deriving this background ▷

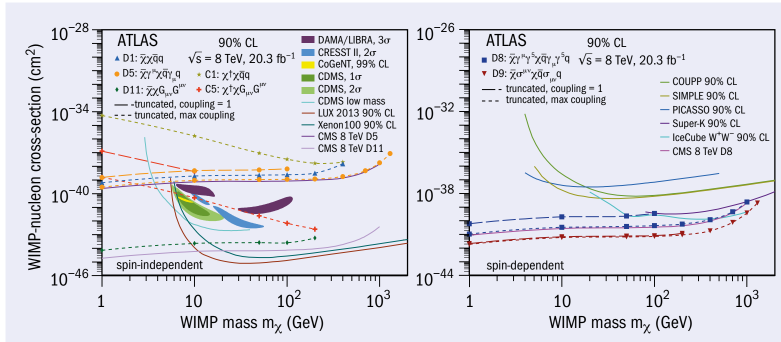
News

from data samples of W and Z bosons decaying to charged leptons, the analysis achieves a total background uncertainty in the result of 3–14%, depending on the transverse momentum.

To compare with non-collider searches for weakly interacting massive particle (WIMP) dark matter, the limits from this analysis have been translated via an effective field theory into upper limits on WIMP–nucleon scattering or on WIMP annihilation cross-sections. When the WIMP mass is much smaller than several hundred giga-electron-volts – the kinematic and trigger thresholds used in the analysis – the collider results are approximately independent of the WIMP mass. Therefore, the results play an important role in constraining light dark matter for several types of spin-independent scattering interactions (see figure). Moreover, collider results are insensitive to the Lorentz structure of the interaction. The results shown on spin-dependent interactions are comparable to the spin-independent results and significantly stronger than those of other types of experiments.

The effective theory is a useful and general way to relate collider results to other dark-matter experiments, but it cannot always be employed safely. One advantage of the searches at the LHC is that partons can collide with enough energy to resolve the mediating interaction directly, opening complementary ways to study it. In this situation, the effective theory breaks down, and simplified models specifying an explicit mediating particle are more appropriate.

The new ATLAS monojet result is



Upper limit on the dark-matter–nucleon scattering cross-section from the monojet analysis

sensitive to dark-matter production rates where both effective theory and simplified-model viewpoints are worthwhile. In general, for large couplings of the mediating particles to dark matter and quarks, the mediators are heavy enough to employ the effective theory, whereas for couplings of order unity the mediating particles are too light and the effective theory is an incomplete description of the interaction. The figures use two types of dashed lines to depict the separate ATLAS limits calculated for these two cases. In both, the calculation removes the portion of the signal cross-section that depends on the internal structure of the mediator, recovering a well-defined and general but conservative limit from the effective theory. In addition, the new result presents constraints on dark-matter production within one possible simplified model, where the mediator of the interaction is a Z′-like boson.

While the monojet analysis is generally the most powerful search when the accompanying Standard Model particle is radiated from the colliding partons, ATLAS has also employed other Standard Model particles in similar searches. They are especially important when these particles arise from the dark-matter interaction itself. Taken together, ATLAS has established a broad and robust programme of dark-matter searches that will continue to grow with the upcoming data-taking.

Further reading

ATLAS Collaboration 2014 CERN-PH-EP-2014-299, to be submitted to *Eur. Phys. J. C*.
ATLAS Collaboration 2014 arXiv:1411.1559 [hep-ex], accepted by *Phys. Rev. D*.
ATLAS Collaboration 2014 arXiv:1410.5404 [hep-ex], accepted by *Eur. Phys. J. C*.
ATLAS Collaboration 2014 arXiv:1410.4031 [hep-ex], submitted to *Eur. Phys. J. C*.

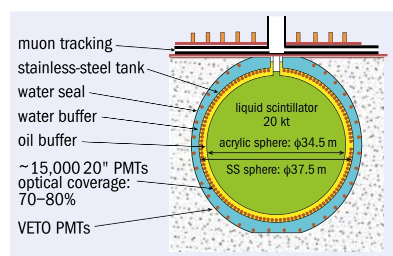
FACILITIES

Ground breaking for China's new neutrino observatory

On 10 January, the ground-breaking ceremony for the Jiangmen Underground Neutrino Observatory (JUNO) took place in Jiangmen City, Guangdong Province, China. More than 300 scientists and officials from China and other countries attended and witnessed this historical moment.

JUNO is the second China-based neutrino project, following the Daya Bay Reactor experiment, and is designed to determine the neutrino mass-hierarchy via precision measurements of the reactor-neutrino energy spectrum. The experiment is scheduled to start data-taking in 2020 and is expected to operate for at least 20 years. The neutrino detector, which is the experiment's core component, will be the world's largest and highest-precision liquid scintillator detector.

After the determination of the θ_{13} mixing angle by Daya Bay and other experiments, the next challenge to the international neutrino community is to determine the neutrino-mass hierarchy. Sensitivity analysis shows that the preferred range for the experiment stations is 50–55 km from a nuclear reactor. Jinji Town, the detector site chosen for the JUNO experiment, is 53 km from both Yangjiang and Taishan Nuclear Power Plants, which provide a total thermal power of 35.8 GW. By 2020, the effective power will be the highest in the world.



The JUNO detector is designed to be located deep underground in a tunnel, with a total overburden of 700 m of rock to suppress muon-induced backgrounds.

The JUNO international collaboration, established on 28 July 2014, already consists of more than 300 members from 45 institutions in nine countries and regions, and more than 10 institutions from five countries are planning to join.

Sciencewatch

Compiled by John Swain, Northeastern University

'Hedgehog particles' to help the environment

Maintaining colloidal suspensions is done typically by coating particles with, for example, surfactants, organic tethers or polymers, which have an affinity for the solvent and help the colloidal particles to repel each other. A new approach is based on the shape of the colloidal-particle surfaces, corrugating them to make them look like tiny hedgehogs.

Joong Hwan Bahng and colleagues in Nicolas Kotov's group of the University of Michigan in Ann Arbor attached nanoscale ZnO spikes to carboxylated polystyrene microspheres. The spikes of the distinct "hedgehogs" made this way do not interpenetrate, and a complex combination of effects, including trapped air and solvent autoionization, provides colloidal stability via physical effects. These findings could help to reduce the use of environmentally unpleasant solvents and surfactants, just by suitable roughening of the colloid surfaces.

This coloured electron-microscope image of "hedgehog" particles by PhD student J H Bahng took top prize in the Materials Research Society's Science as Art competition in 2013. (Image credit: Materials Research Society.)

● **Further reading**
J H Bahng *et al.* 2015 *Nature* **517** 596.

Quantum memory sticks?

Quantum information offers the possibility of unbreakable encryption. Manjin Zhong of the Australian National University in Canberra and colleagues have now made a quantum hard-drive with storage time 100 times better than possible previously. Using a ground-state hyperfine transition of europium ions in yttrium orthosilicate, and optically detected nuclear magnetic resonance techniques, the researchers achieved a decoherence rate for qubits of 8×10^{-5} per second over 100 ms – the timescale for light transmission at a global scale.

With dynamic decoupling, they reached coherence times of 370±60 minutes at 2 K. This is six hours of quantum storage, making it possible to imagine carrying quantum information in the future not via photons, but stored on quantum memory sticks. In addition to its obvious commercial importance, this work also opens the way to tests of quantum entanglement over very long distances.

● **Further reading**
M Zhong *et al.* 2015 *Nature* **517** 177.

Antibiotics without resistance

Most modern antibiotics were derived from screening cultured soil organisms, but today this source seems close to being wiped out, and many strains of dangerous bacteria have become resistant. Uncultured organisms are 99 times more numerous in nature, and new techniques have been developed recently to grow them in their natural environment – with some amazing results.

Kim Lewis of Northeastern University in Boston and colleagues in the US, Germany and the UK have isolated a new cell-wall inhibitor, teixobactin, from such uncultured bacteria. Amazingly, it seems to trigger no detectable genetic resistance in the bacteria that it attacks. The reason may be that it targets lipids, which cells synthesize from precursors, rather than proteins, which are coded for directly by genes, and are susceptible to mutation. This could lead to families of new antibiotics to which bacteria have little chance of developing resistance.

● **Further reading**
L L Ling *et al.* 2015 *Nature* **517** 455.

Electrostatic charging of identical insulators

That identical insulators, brought into contact and separated, can develop charges, has been a long-standing mystery, known since ancient Greece. Lightning-like discharges in sandstorms, volcanic-dust plumes and grain and coal plants are all well-known phenomena, but have defied complete explanation.

Now, Yanzhen Zhang of the China University of Petroleum in Qingdao and colleagues have shown that for this to happen, a small amount of water and a small pre-existing electric field are all that are needed, breaking the symmetry of the insulators being identical. The charge separation seems to be driven by the ionization of surface-adsorbed water, and explains why wind-blown sand produces electrical discharges only if a thunderstorm is nearby.

● **Further reading**
Y Zhang *et al.* 2015 *Phys. Rev. X* **5** 011002.

Sodium explosions

Almost everyone who has had an introductory chemistry course has seen a piece of sodium or potassium tossed into water and watched it react, bursting into flames and exploding, but only now is a picture emerging of what goes on. Explosions normally require good mixing of reactants, but this is a surface reaction, and it would be reasonable to expect self-quenching from the products, with the steam and hydrogen released also forming a buffering layer.

Pavel Jungwirth of the Academy of Sciences of the Czech Republic in Prague and colleagues took high-speed pictures of liquid droplets of Na/K alloy falling into water, and discovered anything but typical explosions. Electrons are released almost immediately from the surface (which is visible as a blue colouration if ammonia is used in place of water), leaving the droplet charged. It grows spikes of metal on a sub-millisecond timescale, and then undergoes a "Coulomb explosion" where electrostatic repulsion reaches the Rayleigh limit, tearing the droplet apart and exposing more surface, therefore hastening the reaction and causing the well-loved explosion.

● **Further reading**
P E Mason *et al.* 2015 *Nature Chemistry* DOI: 10.1038/NCHEM.2161.

Astrowatch

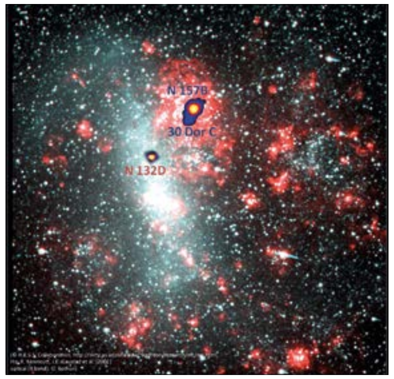
Compiled by Marc Türler, ISDC and Observatory of the University of Geneva, and CHIPP, University of Zurich

HESS sees a powerful trio in a nearby galaxy

The High Energy Stereoscopic System (HESS) has discovered three extremely luminous gamma-ray sources in the Large Magellanic Cloud (LMC) – a dwarf galaxy orbiting the Milky Way about 170,000 light-years away. The three objects are all exceptional. They comprise the most powerful supernova remnant and pulsar-wind nebula, as well as a superbubble – a new class of source in very high-energy (VHE) gamma rays.

The HESS array of telescopes, located in Namibia, observes flashes of Cherenkov light emitted by particle showers triggered by incident gamma rays in the upper atmosphere (*CERN Courier* January/February 2005 p30). This technique is sensitive to gamma rays at energies of tera-electron-volts – photons typically a thousand times more energetic than those observed by the Fermi Gamma-ray Space Telescope in the giga-electron-volt range (*CERN Courier* November 2008 p13). These high-energy photons are emitted by extremely energetic particles interacting with matter or radiation. They are therefore the best tracers of cosmic accelerators such as supernova remnants and pulsar wind nebulas – two different types of remains from the evolution of massive stars.

Resolving individual sources in a galaxy outside of the Milky Way is a new breakthrough for Cherenkov-telescope astronomy. HESS performed a deep observation of the largest star-forming region within the LMC, known as the Tarantula Nebula (Picture of the month, *CERN Courier* June 2012 p12). The 210 hours of observation yielded the discovery of the three extremely energetic objects.



The HESS sky map with labelled sources of VHE gamma rays superimposed on a composite optical and Hα image of the LMC. (Image credit: H.E.S.S. Collaboration/Hα: R Kennicutt, J E Gaustad et al. *(2001)/optical (B-band): G Bothun.)*

One of the new sources is the superbubble 30 Dor C. It is the first time that a superbubble has been detected in the VHE regime, and demonstrates that the objects are a source of highly energetic particles. With a diameter of 270 light-years, 30 Dor C is the largest-known X-ray-emitting shell, and appears to have been blown by several supernovas and strong stellar winds from massive stars. The detection by HESS is important because it shows that superbubbles are viable sources of galactic cosmic rays, complementary to individual supernova remnants (*CERN Courier* April 2013 p12).

Another source detected by HESS is the pulsar-wind nebula N 157B. This kind of nebula is formed by the wind of ultra-relativistic particles blown by a pulsar – a highly magnetized, rapidly spinning neutron star. The most famous is the Crab Nebula, one of the brightest sources in the gamma-ray sky (*CERN Courier* November 2008 p11). N 157B is similar, but outshines the Crab Nebula by an order of magnitude in VHE gamma rays, owing to a lower magnetic field and a stronger radiation field from neighbouring star-forming regions.

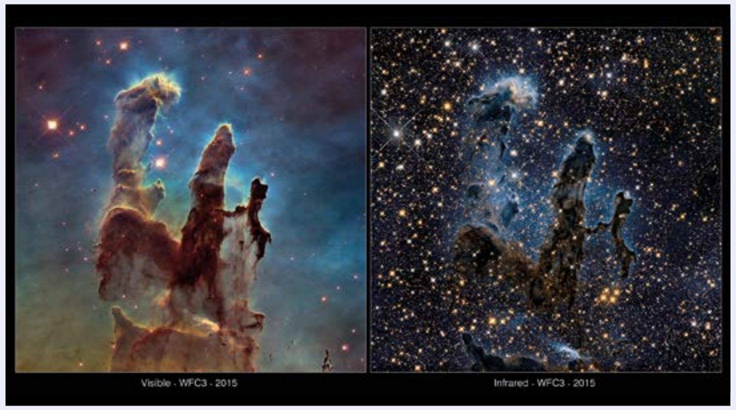
The third object is the supernova remnant N 132D, which is already known as a bright object in the radio and infrared wavebands. Although it is between 2500 and 6000 years old, it still outshines the strongest supernova remnants in the Galaxy in the VHE regime. Surprisingly, the remnant of the bright supernova SN 1987A – which exploded in the LMC 28 years ago – was not detected by HESS, in contrast to theoretical predictions. The current study published in *Science* shows the LMC to be a prime target for even deeper observations with the new HESS II 28-m telescope and the future Cherenkov Telescope Array (*CERN Courier* July/August 2012 p28).

● Further reading

HESS Collaboration 2015 *Science* **347** 406.

Picture of the month

To celebrate its 25th anniversary, the Hubble Space Telescope released two new images of the "Pillars of Creation". These backlit formations of gas and dust in the centre of the Eagle Nebula (Messier 16) were first explored by Hubble in 1995 (Picture of the month, *CERN Courier* March 2007 p11). The original image soon became one of its most famous views of the sky. This view is now extended and sharpened in visible light (left) and complemented in the infrared (right), thanks to the installation of the Wide Field Camera 3 by astronauts in 2009. In infrared, the iconic pillars are transformed into wispy silhouettes set against a background peppered with stars, making visible new-born stars forming within them. (Image credit: NASA, ESA/Hubble and the Hubble Heritage Team.)



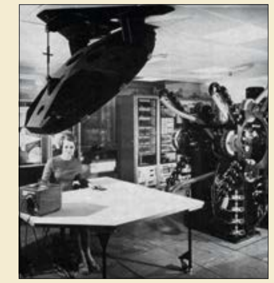
CERN Courier Archive: 1972

A look back to CERN Courier vol. 12, March 1972, compiled by Peggie Rimmer

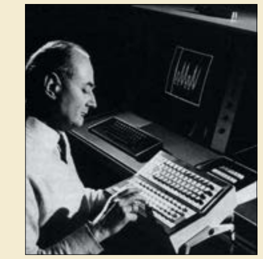
Special issue

Computing at CERN

CERN's new central computer, a CDC 7600, being wheeled across the tarmac at Geneva airport in mid-February. (Image credit: CERN 165.2.72.)



A view of a Lecteur à Spirale Digitisée LSD measuring machine (Spiral Reader). (Image credit: CERN 721.1.69.)



A physicist using GAMMA, a fully interactive, general purpose, Graphically Aided Mathematical Machine, allowing the user to manipulate his own algorithms in dialogue with the computer. Some of the basic functions available are sine, cosine, exponent, log, etc. (Image credit: CERN 141.12.68.)

Since 1950, particle physics happened to be the most richly endowed domain of basic research. Secure in their ability to pay, high-energy physicists were not slow to recognize those features of their science which put them in the forefront among potential users of computing hardware and software.

Details of "how" and "what for" show the way for similar developments in other branches of science. In this respect, as in many others, CERN's pioneering influence may transcend the organization's basic function as a centre of research in high-energy physics.

● From "Why?" by L Kowarski, pp60–61.

The central computing service operates 24 hours per day, seven days per week. It is predominately batch oriented, the main languages being FORTRAN and assembly language. A large program and subroutine library is available on disk, and a tape library of some 35,000 reels is maintained close to the central computers.

Batch input/output using card readers and line printers is via three remote self-operated input/output stations (RIOS) as well as at the central computers. In addition, there is a car delivery service to a number of remote parts of CERN.

● From "Central computing" by D Ball, p63.

Computers are used in three types of system for measuring particle interactions in bubble chambers photographed on film. All require operator intervention and (the first) two record the digitised tracks on magnetic tape for off-line analysis.

The HPD (Hough Powell Device, named for its originators) is a raster-scan system with an optical-mechanical spot scanning the film.

The LSD (Lecteur à Spirale Digitisée, the Spiral Reader developed at Berkeley) performs a spiral scan around the vertex of the measured event with an optical-mechanical slit. Because the LSD measures the three [stereo] views at the same time, the output of the off-line analysis can be obtained within a few days.

A hand-operated system called RAMSES (ReActive Measurement Scanning and Evaluation System) is used exclusively for measuring and analyzing very complicated events from the Gargamelle 4.5 m heavy liquid bubble chamber.

● From "Data acquisition from film" by W Blair and J C Gouache, pp72–73.

Over the past 10 years, a chain of three analysis programs, THRESH, GRIND and SLICE, has been used for off-line analysis. Each one is a self contained FORTRAN program with data communication between the programs via magnetic tape. In 1970 a decision was taken to make a clean break in preparation for measuring photographs from the 3.7 m bubble chamber BEBC, scheduled to become operational at CERN in 1972.

The new program system, HYDRA, has a maximum of simplicity and a minimum of concepts. Its services, requested with CALL statements, are, in a sense, an extension of FORTRAN. HYDRA should help to tear down the walls that have sometimes threatened to separate physicists from computer specialists, or bubble-chamber groups from each other and from physicists using other techniques.

● From "Bubble-chamber data analysis" by R K Böck and J Zoll, pp70–71.

Theoretical physicists mostly use computers for numerical valuation, with programs requiring only a library of special functions, a card reader for input and a line printer for output. About 80% of them would, in fact, be better off interacting with an "advanced desk calculator" [e.g. GAMMA].

A more exotic use of the computer is in the field of algebraic manipulations, for instance, the evaluation of Feynman graphs in quantum electrodynamics and related fields. At CERN, a large-scale algebraic manipulation program (SCHOONSCHIP) was written by a single person, M Veltman from Utrecht [physics Nobel laureate 1999], in the middle of the 1960s.

● From "Theoretical studies" by B Lautrup, p81.

Compiler's Note

The March 1972 *CERN Courier* was dedicated to computing, and these extracts have been selected from an impressive set of articles by 21 CERN gurus. They have been chosen to capture the prevailing *espirit de corps*, and to show junior members of our community from just how far back we have come! And here is an off-line nugget: the CDC 7600, one of the last machines to have individual components soldered onto circuit boards, had a peak performance of some 36 MFLOPS, matched by an iPhone 4. It cost $5 million, some $30 million in today's dollars.

XFELs in the study of biological structure

The femtosecond pulses and astonishing peak brilliance of X-ray free-electron lasers are enabling whole new classes of experiments for imaging biological structures.

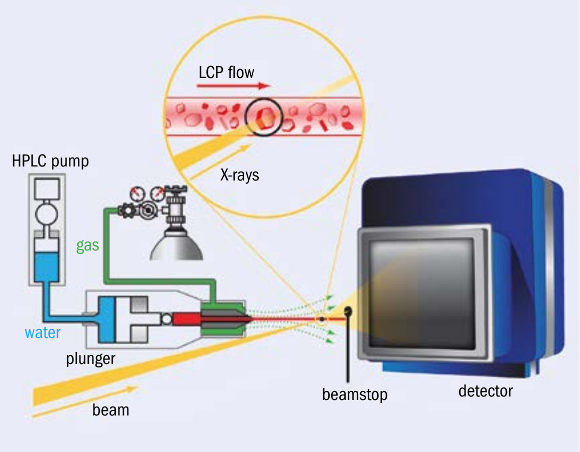


Fig 1. Experimental set-up for membrane protein SFX. (Image credit: Uwe Weierstall/Reproduced with permission, P Nogly et al. *2015* IUCrJ **2** *doi:10.1107/S2052252514026487.)*

INTERNATIONAL YEAR OF LIGHT 2015

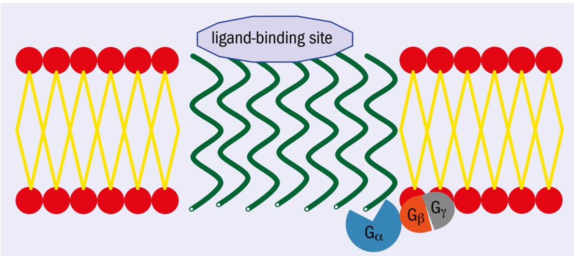
The Linac Coherent Light Source (LCLS) at SLAC produced its first laser-like X-ray pulses in April 2009. The unique and potentially transformative characteristics of the LCLS beam – in particular, the short femtosecond pulse lengths and the large numbers of photons per pulse (see box, p22) – have created whole new fields, especially in the study of biological materials. X-ray diffraction on nanocrystals, for example, reveals 3D structures at atomic resolution, and allows pump-probe analysis of functional changes in the crystallized molecules. New modalities of X-ray solution scattering include wide-angle scattering, which provides detailed pictures from pump-probe experiments, and fluctuational solution scattering, where the X-ray pulse freezes the rotation of the molecules in the beam, resulting in a rich, 2D scattering pattern. Even the determination of the structure of single particles is possible. This article focuses on examples from crystallography and time-resolved solution scattering.

An important example from crystallography concerns the structure of protein molecules. As a reminder, protein molecules, which are encoded in our genes, are linear polymers of the 20 naturally occurring amino-acid monomers. Proteins contain hundreds or thousands of amino acids and carry out most functions within cells or organs. They catalyse chemical reactions; act as motors in a variety of contexts; control the flow of substances into and out of cells; and mediate signalling processes. Knowledge of their atomic structures lies at the heart of mechanistic understanding in modern biology.

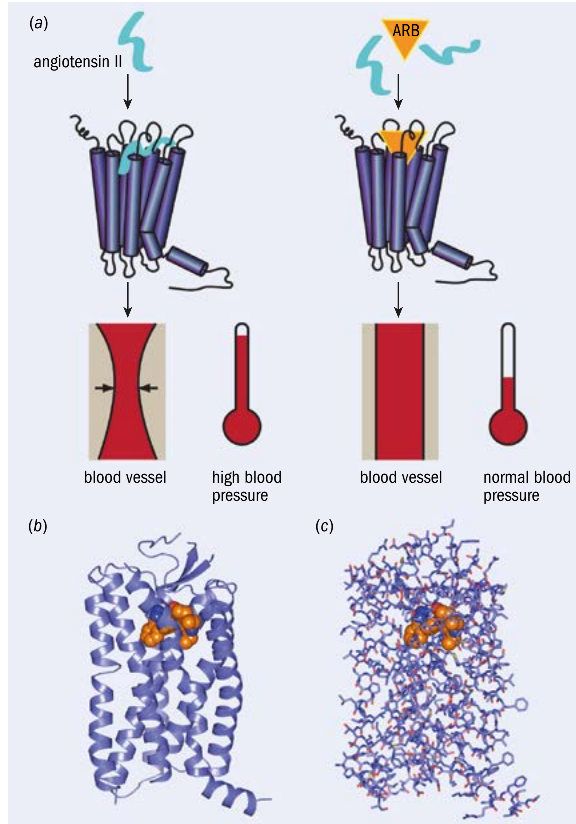
Forming usable crystals of a protein of interest is by far the most restrictive bottleneck in crystallography. Often crystals grow to a limiting size that is too small to use at third-generation synchrotron X-ray sources. The ability of the X-ray free-electron laser (XFEL) to investigate these tiny crystals is now greatly expanding the universe of molecules that can be studied by crystallography.

Serial femtosecond crystallography (SFX) provides a method of studying the structure of proteins. In SFX, still X-ray photographs are obtained from a stream of nanocrystals, each crystal being illuminated by a single pulse of a few femtoseconds duration. At the LCLS, the 10^{12} photons per pulse can produce observable diffraction from a protein crystal much less than 1 μm^3. Critically, a 10 fs pulse will scatter from a specimen before radiation damage takes place, thereby eliminating such damage as an experimental issue. Figure 1 shows a typical SFX set-up for crystals of membrane proteins. The X-ray beam in yellow illuminates a stream of crystals, shown in the inset, being carried in a thin stream of highly viscous cubic-phase lipid (LCP). The high-pressure system that creates the jet is on the left. The rate of LCP flow is well matched to the 120 Hz arrival rate of the X-ray pulses, so not much material is wasted between shots. In the ideal case, each X-ray pulse scatters from a single crystal in the LCP flow. For soluble proteins, a jet of aqueous buffer replaces the LCP.

A good example that demonstrates both the advantages and the actual successes of the LCLS for crystallography is given by recent results for the membrane protein angiotensin II type 1 receptor (AT1R) – a member of an important family of membrane proteins called G-protein coupled receptors (GPCRs). About 800 different GPCRs are coded by the human genome, and some 40 per cent of approved drugs target GPCRs. As figure 2 (p20) illustrates, an important GPCR function is to bind a signalling molecule at the ▷



Above: Fig. 2. Schematic of a GPCR embedded in a membrane. Red balls represent polar phospholipid groups and yellow lines extended hydrocarbon chains. Hormones or other effectors occupy the ligand-binding site, transmitting a structural change through the seven protein α-helices (green) of the receptor to the three sub-units, α, β and γ, of the G-protein. The effect allows G_α to bind the high-energy compound GTP, whose energy is mobilized to produce a variety of effects within the cell.



Right: Fig. 3. The structure and function of AT1R. (a) Blue cylinders represent seven trans-membrane helices, as shown in figure 2. The binding of angiotensin to the receptor site leads to the constriction of blood vessels and the elevation of blood pressure. The binding of the AT1R blocker ZD7155 (orange triangle) inhibits this process. (b) The AT1R structure, showing the paths of the helices in space with an atomic model of ZD7155. (c) The same as (b) but including all atoms except hydrogen. Atoms are drawn smaller than true relative size for clarity, except ZD7155 is drawn with van der Waals radii. (Image credit: Vadim Chezerov.)

exterior of a cell, and transduce this binding to the interior to produce an appropriate response. The cell membrane is a lipid bilayer a few nanometres thick that surrounds all cells, providing a critical barrier between the inside and outside. Most proteins are water soluble, but those that are localized in the membrane can be solubilized by detergents or lipids only, and they are notoriously difficult to crystallize.

AT1R is found at the surface of vascular cells and serves as the principal regulator of blood pressure (figure 3). Although several AT1R blockers (ARBs) have been developed as anti-hypertensive drugs, the structural knowledge of the binding to AT1Rs has been lacking, owing mainly to the difficulties of growing high-quality crystals for structure determination. Using SFX at the LCLS, Vadim Cherezov and colleagues have successfully determined the room-temperature crystal structure of human AT1R in a complex with its selective receptor-blocker ZD7155 at 2.9 Å resolution (Zhang *et al*. 2015). The structure of the AT1R–ZD7155 complex reveals key features of AT1R and critical interactions for ZD7155 binding. Docking simulations, which predict the binding orientation of clinically used ARBs onto the AT1R structure, further elucidated both the common and distinct binding modes for these anti-hypertensive drugs. The results have provided fundamental insights into the AT1R structure-function relationship and structure-based drug design.

In solution scattering, an X-ray beam illuminates a volume of solution containing a large number of the particles of interest, creating a diffraction pattern. Because the experiment averages across many rotating molecules, the observed pattern is circularly symmetric and can be encapsulated by a radial intensity curve, I(q), where $q = 4\pi\sin\theta/\lambda$ and 2θ is the scattering angle. The data are therefore essentially one-dimensional (figure 4b). The I(q) curves are quite smooth and can be well described by a modest number of parameters. They have traditionally been analysed to yield a few important physical characteristics of the scattering particle, such as its molecular mass and radius of gyration. Synchrotrons have enabled new classes of solution-scattering experiments, and the advent of XFEL sources is already providing further expansion of the methodology.

Chasing the protein quake

An elegant example of time-resolved wide-angle scattering (WAXS) at the LCLS comes from a group led by Richard Neutze at the University of Gothenburg (Arnlund *et al*. 2014), which has used multi-photon absorption to trigger an extremely rapid structural perturbation in the photosynthetic reaction centre from *Blastochloris viridis*, a non-sulphur purple bacterium that produces molecular oxygen valuable to our environment. The group measured the progress of this fluctuation using time-resolved WAXS. Appearing with a time constant of a few picoseconds, the perturbation falls away with a 10 ps time constant and, importantly, precedes the propagation of heat through the protein.

The photosynthetic reaction centre faces unique problems of energy management. The energy of a single photon of green light is approximately equal to the activation energy for the unfolding of the protein molecule. In the photosynthetic complex, photons are absorbed by light-harvesting antennae and then rapidly funnelled to the reaction centre through specialized channels. The hypothesis is that excess energy, which may also be deposited in the protein, is dissipated before damage can be done by a process named "a protein quake", indicating a nanoscale analogue of the spreading of waves away from the epicentre of an earthquake.

The experiments performed at the coherent X-ray imaging (CXI) station at the LCLS used micro-jet injection of solubilized protein samples. An 800 nm laser pulse of 500 fs duration illuminating the sample was calibrated so that a heating signal could be observed in the difference between the WAXS spectra with and without the laser illumination (figure 5a). The XFEL was operated to produce 40 fs pulses at 120 Hz, and illuminated and dark samples were interleaved, each at 60 Hz. The team calibrated the delay time between the laser and XFEL pulses to within 5 ps, and collected scattering patterns across a series of 41 time delays to a maximum of 100 ps. Figure 5b shows the curves indicating the difference in scattering between activated and dark molecules that were generated at each time point.

The results from this study rely on knowing the equilibrium molecular structure of the complex. Molecular-dynamics (MD) simulations and modelling play a key role in interpreting the data and developing an understanding of the "quake". A combination of MD simulations of heat deposition and flow in a molecule and spectral decomposition of the time-resolved difference scattering curves provide a strong basis for a detailed understanding of ▷

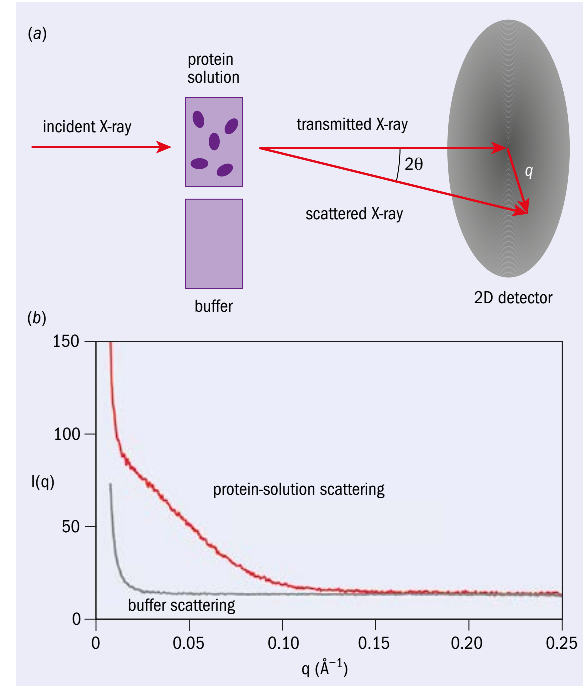


Fig. 4. (a) Experimental set-up for a small-angle X-ray-scattering experiment, showing the X-ray beam, with specimen comprising protein solution and buffer blank, and the resulting azimuthally averaged scattering pattern. (b) Radial trace through patterns from protein solution and buffer, showing scattered intensity, I, as a function of $q = 4\pi\sin\theta/\lambda$. Protein-solution scattering goes far off scale at low angles. Buffer scattering is flat, reflecting the featureless character of the solvent. Proteins with significantly different structures yield distinguishable I(q) curves. (Image credit: Reproduced with permission, S Skou et al. *2014* Nature Protocols **9** *1727.)*

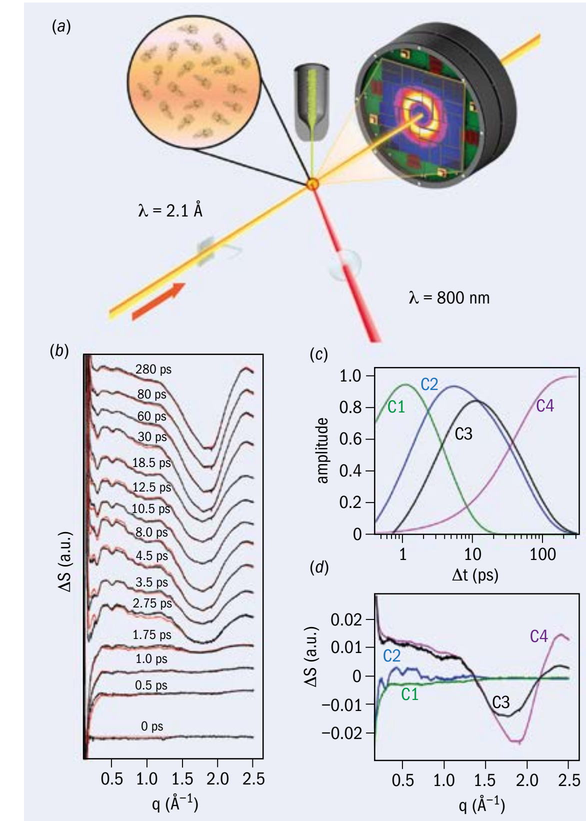


Fig. 5. (a) Experimental set-up illustrating the microjet of solubilized microcrystals of the photosynthetic reaction centre from Blastochloris viridis *(green), the X-ray detector, XFEL beam (orange) and 800-nm pump laser (red). (b) Time-resolved WAXS difference data, $\Delta S(q, \Delta t) = S_{light}(q, \Delta t) - S_{dark}(q)$, as a function of the time delay between the arrival of the pump laser and the XFEL probe, for 15 time delays. Linear sums of the four basis spectra (red) shown in (d) are superimposed upon the experimental difference data (black). (c) Time-dependent amplitudes of the components C1–C4 used to extract the basis spectra. (d) Basis spectra extracted from the experimental data by spectral decomposition: C1, an ultrafast component (green); C2, a protein component (blue); C3, non-equilibrated (black) heating component; C4, equilibrated (magenta) heating component. (Image credit: Reproduced with permission from Arlund* et al.*)*

The LCLS XFEL

Hard X-ray free-electron lasers (XFELs) are derived from the undulator platform commonly used in synchrotron X-ray sources around the world. In the figure, right, (*a*) shows the undulator lattice, which comprises a series of alternating pairs of magnetic north and south poles defining a gap through which electron bunches travel. The undulator at the LCLS is 60 m long, compared with about 3 m for a synchrotron device. The bunches experience an alternating force normal to the magnetic field in the gap, transforming their linear path into a low-amplitude cosine trajectory.

In the reference frame of the electron bunch, the radiation that each electron emits has a wavelength equal to the spacing of the undulator magnets (a few centimetres) divided by the square of the relativistic factor $\gamma = E/m_e^2$ (see below). Each electron interacts both with the radiation emitted by electrons preceding it in the bunch, and with the magnetic field within the undulator. Initially, the N electrons in the bunch have random phases (see figure, (*b*)), so that the radiated power is proportional to N.

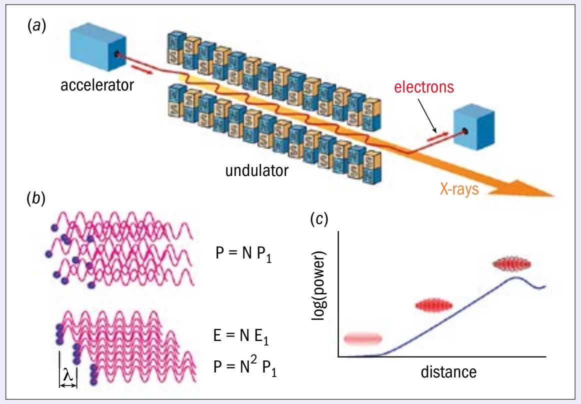
As the bunch advances through the undulator, it breaks up into a series of microbunches of electrons separated by the wavelength of the emitted radiation. Without going into detail, this microbunching arises from a Lorenz force on the electron in the direction of propagation, which is generated by the interaction of the undulator field and the (small) component of the electron velocity perpendicular to the direction of propagation. This force tends to push the electrons into a position at the peak of the emitted radiation. All electrons within a single bunch radiate coherently, and the radiation from one microbunch is also coherent with that from the next, being separated by a single wavelength. Therefore, the power in the radiated field is proportional to N^2.

The process of microbunching can be viewed as a resonance process, for which the following undulator equation describes the conditions for operation at wavelength λ:

$$\lambda = \left(1 + \frac{K^2}{2}\right)\frac{\lambda_u}{2\gamma^2}.$$

Here, λ_u is the undulator magnet period (magnet period), and K is a dimensionless, lumped undulator parameter given by $eB_0\lambda_u/2\pi mc$. B_0 is the peak undulator field.

The tables, right, show typical operating conditions for the CXI beamline at the LCLS. The values represent only a small subset of possible operating conditions. Note the small source size, the short pulse duration and the high photons per pulse.



Above right: Schematic of the X-ray lasing process. (Image credit: Published with permission from B D Patterson et al. *2010* PCCP **12** *647.)*

Source parameters	
Photon energy	5–10 keV for the 1st harmonic*
	up to 25 keV for 2nd and 3rd harmonics
Source size	$60 \times 60\,\mu m^2$ (HxV) FWHM @ 8.3 keV
	$78 \times 78\,\mu m^2$ (HxV) FWHM @ 2 keV
Source divergence	$2 \times 2\,\mu rad^2$ (HxV) FWHM @ 8.3 keV
	$\sim 7 \times 7\,\mu rad^2$ (HxV) FWHM @ 2 keV
Repetition rate	120, 60, 30 and 10 Hz, single-shot mode
Pulse duration	40–300 fs (high-charge mode)
	< 10 fs (low-charge mode)
Pulse energy	1–3 mJ (high-charge mode)
	~0.2 mJ (low-charge mode)
Photons per pulse	$\sim 1 \times 10^{12}$ (high-charge mode @ 8.3 keV)

LCLS photon-beam properties	
Beam size at sample (8 keV)	$1.3 \times 1.3\,\mu m^2$ FWHM with 1 μm KB pair (KB1)
(Calculated for perfect optics)	$90 \times 150\,nm^2$ FWHM (V × H) with 100 nm KB pair (KB01)
Beam divergence	$\sim 0.3 \times 0.3\,mrad^2$ FWHM with Hutch 5 Be lenses
(Calculated for perfect optics)	$2 \times 2\,\mu rad^2$ FWHM unfocused beam

the energy propagation in the system. Because the light pulse was tuned to the frequency of the photosystem's antennae, cofactors (molecules within the photosynthetic complex) were instantaneously heated to a few thousand kelvin, before decaying with a half-life of about 7 ps through heat flow to the remainder of the protein. Also, principal component analysis revealed oscillations in the range $q = 0.2–0.9\,nm^{-1}$, corresponding to a crystallographic resolution of 31–7 nm, which are signatures of structural changes in the protein. The higher-angle scattering – corresponding to the heat motion – extends to a resolution of a few angstroms, with a time resolution extending to a picosecond. This study illustrates not only the rapid evolution of the technology and experimental prowess of the field, but brings it to bear on a problem that makes clear the biological relevance of extremely rapid dynamics.

Effective single-particle imaging (SPI) would eliminate the need for crystallization, and would open new horizons in structure determination. It is an arena in which electron microscopy is making great strides, and where XFELs face great challenges. Simulations have demonstrated the real possibility of recovering structures from many thousands of weak X-ray snapshots of

molecules in random orientation. However, it has become clear, as actual experiments are carried out, that there are profound difficulties with collecting high-resolution data – at present the best resolution in 2D snapshot images is about 20 nm. A recent workshop on single-particle imaging at SLAC identified a number of sources of artifacts including complex detector nonlinearities, scattering from apertures, scattering from solvent, and shot-to-shot variation in beam intensity and position. In addition, the current capability to hit a single molecule with a pulse reliably is quite limited. Serious technical progress at XFEL beamlines will be necessary before the promise of SPI at XFELs is realized fully.

Currently, the only operational XFEL facilities are at the SPring-8 Angstrom Compact free-electron LAser (SACLA) at RIKEN in Japan (*CERN Courier* July/August 2011 p9) and the LCLS in the US, so competition for beamtime is intense. Within the next few years, the worldwide capacity to carry out XFEL experiments will increase dramatically. In 2017, the European XFEL will come on line in Hamburg, providing a pulse rate of 27 kHz compared with the 120 Hz rate at the LCLS. At about the same time, facilities at the Paul Scherrer Institute in Switzerland and at the Pohang Accelerator Laboratory in South Korea will produce first light. In addition, the technologies for performing and analysing experiments are improving rapidly. It seems more than fair to anticipate a rapid growth in crystallography, molecular movies, and other exciting experimental methods.

Further reading

D Arnlund *et al.* 2014 *Nature Methods* **11** 923.
H Zhang *et al.* 2015 *Science* in press.
For reviews of the development of XFELs and their applications, see
W A Barletta *et al.* 2010 *Nucl. Instrum. and Meth. A* **618** 69.
A Barty *et al.* 2013. *Annu. Rev. Phys. Chem.* **64** 415.
J C Spence *et al.* 2012 *Rep. Prog. Phys.* **75** 102601.
P Thibault and V Elser 2010 *Ann. Rev. Cond. Mat. Phys.* **1** 237.

Résumé

Les lasers XFEL pour sonder la structure biologique

Grâce à leurs impulsions femtoseconde et à leur incroyable brillance crête, les lasers à électrons libres à rayons X (XFEL) ouvrent la voie à de nouveaux types d'expériences d'imagerie visant à sonder les structures biologiques. L'article porte sur les expériences menées auprès de l'accélérateur linéaire et source de lumière cohérente au SLAC, qui a produit en 2009 ses premières impulsions de rayons X de type laser. Les caractéristiques très particulières du faisceau – notamment les courtes longueurs d'impulsions femtoseconde et le nombre élevé de photons par impulsion – permettent d'explorer de nouveaux domaines, tels que le matériel biologique.

Eaton E Lattman, Hauptman-Woodward Medical Research Institute and BioXFEL Center, University at Buffalo, SUNY. This work was supported by the BioXFEL Center, grant number NSF 1231306. Thanks to Vadim Cherezov for providing a figure and for access to prepublication results, and to Uwe Weierstall and Bruce Patterson for providing figures. John Spence provided helpful criticisms.

A bright future for HERA physics

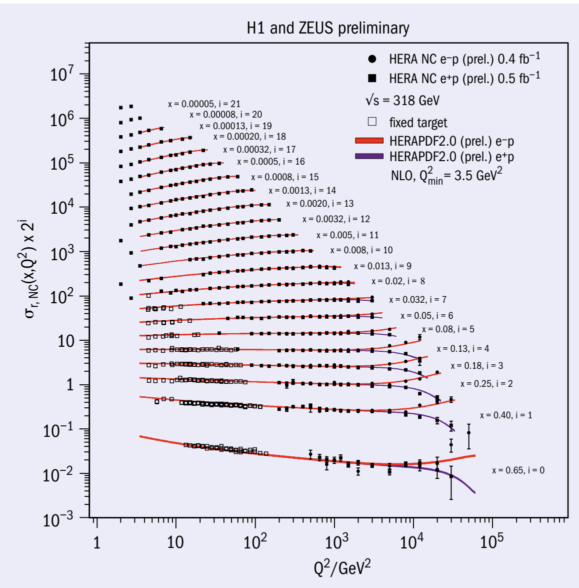
A workshop in DESY looked at what the data from HERA can still offer for experiments, now and in the future.

Even though HERA – the only electron–proton collider built so far – stopped running in mid-2007, analyses of the vast amounts of data from the Hermes, H1 and ZEUS experiments continue to produce important and high-impact measurements relevant to spin physics, the structure of the proton and other areas of QCD. Special efforts have been made to ensure that these unique data are safely preserved for future analyses for at least the next 10 years, within the framework of the Data Preservation in High-Energy Physics collaboration (*CERN Courier* May 2009 p21).

In November 2014, DESY hosted a workshop on "Future Physics with the HERA Data for Current and Planned Experiments", to pull together experts and ask questions about what the HERA data still have to say and how they are relevant to other facilities. The aim was, in effect, to create a list of subjects that are still to be investigated or exploited fully. Across two days, almost 30 presentations and lively discussions occupied around 70 participants, both experimentalists and theorists, from across the globe.

The most recent results from the collaborations and a perspective from theory were presented first in a special HERA symposium, starting with a presentation on recent results from Hermes by Charlotte Van Hulse of the University of the Basque Country. She highlighted the semi-inclusive deep-inelastic scattering (DIS) data collected on a transversely polarized hydrogen target that provides access to various transverse-momentum-dependent parton distribution functions (PDFs), which are sensitive to correlations between quark spin, proton spin, the transverse momentum of quarks and/or of final-state hadrons.

Two talks followed that showed results from H1 and ZEUS, the first on proton structure by Aharon Levy of Tel Aviv University and the second on diffraction and hadronic final states by Alice Valkárová of Charles University, Prague. All of the measurements of inclusive DIS from H1 and ZEUS have been combined recently and QCD fits to these data have been performed, providing a new set of PDFs of the proton (see figure). The 15 years of data taking at HERA have culminated in a combination of 3000 data points, and their impact on knowledge of the structure of the proton will last for years to come. Also, recent jet measurements at HERA have enabled



Combined H1 and ZEUS cross-sections versus exchanged photon virtuality, Q^2, at fixed Bjorken-x for inclusive e^+p and e^-p deep-inelastic scattering using all of the HERA I and II data. Also shown are results from fixed-target experiments and the HERAPDF2.0 QCD fit at next-to-leading order. The data have a precision of about 1% up to Q^2 of around 400 GeV^2, and are well described by theory. Clearly visible are the steep rise of the cross-section at low x – scaling violations – and the electroweak effects at high Q^2 where the e^+p and e^-p cross-sections diverge.

the strong coupling constant to be extracted with an experimental precision of <1%. This has been achieved through the simultaneous measurement of inclusive-jet, dijet and trijet cross-sections.

Providing a theoretical perspective, Robert Thorne of University College London discussed the contribution that data from HERA have made to the understanding of electroweak physics, physics beyond the Standard Model and, in particular, QCD and the structure of the proton. With a crowded auditorium, the symposium went significantly over time because the results shown provoked much discussion that continued into the evening.

The workshop started with general talks from Elke Aschenauer of Brookhaven and Hannes Jung of DESY, both of whom ▷

Workshop

highlighted the need to measure particle production – either inclusively or, even better, by tagging specific particle species – in electron–proton (ep) scattering, differential in four kinematic quantities. Such detailed measurements can be useful in model building and in tuning Monte Carlo simulations, but they can also pin down the transverse-momentum distributions of partons, which are more commonly considered in spin physics. Jung also stressed the contribution that HERA data can make to understanding the nature of multi-parton interactions, by virtue of the unique ability of being able to contrast events in which the colliding photon is either point-like or hadronic-like, thereby turning multi-parton interactions "off" and "on", respectively, within the same experimental set-up.

Updates are needed to Monte Carlo simulations to include the more advanced models for underlying events in ep scattering, as has been done for pp interactions. Simon Plätzer of the Institute for Particle Physics Phenomenology, Durham, discussed recent advances made for the HERWIG++ event generator to include ep processes. He emphasized that the program is ready for comparison with DIS processes, even including the next-to-leading-order matrix elements. As well as a personal perspective, Achim Geiser of DESY provided an extensive list of topics yet to be covered, which anyone interested could look at to see what most excites them.

Given some tension seen between theory and the HERA inclusive data at low photon virtualities, Q^2, and low Bjorken-x, as presented by Levy, several talks, including those by Joachim Bartels of Hamburg University and Amanda Cooper-Sarkar of Oxford University, discussed this region as an avenue for future work. Clearly a joint H1 and ZEUS extraction of the longitudinal structure function, F_L, is needed. Also, the more precise combined data sets now available demand a phenomenological analysis in which the proton structure function, F_2, is parameterized in terms of $x^{-\lambda}$, where the dependence on $-\lambda$ could reveal information on the Pomeron and the applicability of the parton-evolution schemes to describe the structure of the proton.

A highlight of the workshop was the status of next-to-next-to-leading-order (NNLO) QCD predictions of jet production at HERA, presented by Thomas Gehrmann of Zurich University. The use of such predictions will allow more precise comparisons with data and, for example, reduced uncertainties on the extractions of PDFs and the strong coupling constant. The first full predictions and comparison to data for the production of dijets in DIS will be the first NNLO final-state prediction at HERA, and is expected during 2015.

In a wide-ranging talk on diffractive processes, Marta Ruspa of the University of Piemonte Orientale highlighted the crucial questions still to be answered, which relate to the consistency and combination of the H1 and ZEUS data for measurements of inclusive diffraction in DIS. These data allow the extraction of diffractive PDFs (DPDFs) in analogy to the conventional PDFs for inclusive DIS. Using DPDFs, and because factorization should hold, predictions can be made for other processes. The experimental results on the holding of factorization are not conclusive, however, and further investigation of the HERA data would help to clarify this issue and give a better understanding of the mechanism at the LHC, as Bartels indicated.

Ronan McNulty of University College Dublin discussed the overlaps in physics from HERA and the LHCb experiment at CERN, in particular the complementary information on extraction of proton PDFs and the measurement of vector-meson production, particularly J/ψ production, and its sensitivity to the gluon distribution in the proton. Similarly, Sasha Glazov of DESY proposed ideas for common HERA–LHC analyses in the area of PDF extractions and jet physics, where HERA has particularly precise measurements.

Alessandro Bacchetta of the University of Pavia and Emanuele Nocera of the University of Genova highlighted the many pioneering measurements made by the Hermes collaboration in mapping out the helicity and 3D structure of the proton. Open issues include the strange-quark spin content of the proton, electroweak structure functions, etc. These speakers also discussed how the final Hermes analyses, together with results from experiments such as COMPASS at CERN and others at Jefferson Lab and at a future electron–ion collider, could lead to a greater understanding of the complete picture of the structure of the proton.

In a presentation that was relatively technical but very important for this workshop, Dirk Kruecker of DESY outlined the status of the long-term and safe preservation of the HERA data. To ensure that the most is made of this data legacy, the collaborations are open to people outside of the traditional institutes who are interested in analysing the data. To gain access to the data and work on a publication along with a collaboration, interested people should contact the respective spokesperson. A summary document of the workshop will be published in early 2015, and should act as a useful reference for anyone interested in future analyses with the HERA data.

A summary talk by John Dainton of the University of Liverpool provided a thought-provoking and entertaining résumé of some of the highlights of HERA physics, and how they relate to other facilities and fit into the broad context of particle physics. After two intense days, the talks and discussions gave the workshop delegates renewed vigour with which to exploit the HERA data fully during the years to come, and push back the understanding of a rich and wide variety of QCD processes, such as the nature of diffraction and the structure of the proton.

Further reading

For more information about the workshop, visit https://indico.desy.de/conferenceDisplay.py?ovw=True&confId=10523.

Résumé

La physique d'HERA a encore de beaux jours devant elle

Même si HERA, seul collisionneur électron–proton jamais construit à ce jour, a cessé de fonctionner à la mi-2007, les analyses des gigantesques quantités de données des expériences Hermes, H1 et ZEUS continuent d'apporter des informations importantes pour la physique du spin, la structure du proton et d'autres aspects de la chromodynamique quantique. Un atelier organisé en novembre à DESY a permis de réfléchir à ce que les données d'HERA vont pouvoir encore apporter aux expériences à l'avenir. L'objectif était de définir une liste de thèmes méritant d'être étudiés ou approfondis.

Matthew Wing, University College London.

CERN Courier March 2015
Accelerators

A luminous future for the LHC

Work continues apace for the high-luminosity upgrade for the LHC 10 years from now.

To maintain scientific progress and exploit the full capacity of the LHC, the collider will need to operate at higher luminosity. Like shining a brighter light on an object, this will allow more accurate measurements of new particles, the observation of rarer processes, and increase the discovery reach with rare events at the high-energy frontier. The High-Luminosity LHC (HL-LHC) project began in 2011 under the framework of a European Union (EU) grant as a conceptual study, with the aim to increase its luminosity by a factor of 5–10 beyond the original design value and provide 3000 fb^{-1} in 10 to 12 years.

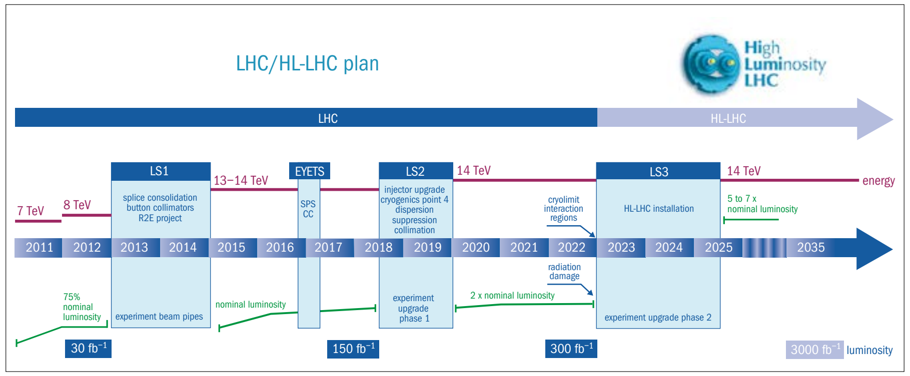
INTERNATIONAL YEAR OF LIGHT 2015

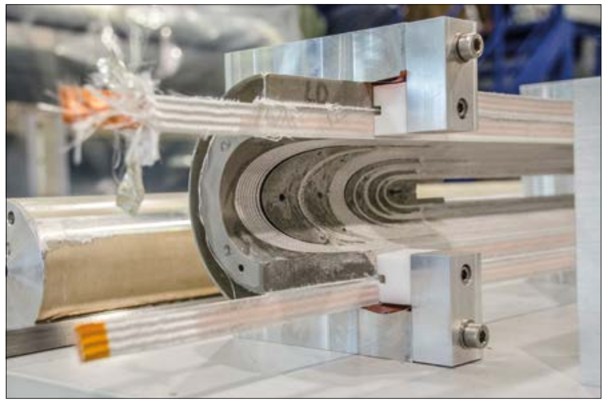
Two years later, CERN Council recognized the project as the top priority for CERN and for Europe (*CERN Courier* July/August 2013 p9), and then confirmed its priority status in CERN's scientific and financial programme in 2014 by approving the laboratory's medium-term plan for 2014–2019. Since this approval, new activities have started up to deliver key technologies that are needed for the upgrade. The latest results and recommendations by the various reviews that took place in 2014 were the main topics for discussion at the 4th Joint HiLumi LHC/LARP Annual Meeting, which was hosted by KEK in Tsukuba in November.

The latest updates

The event began with plenary sessions where members of the collaboration management – from CERN, KEK, the US LHC Accelerator Research Program (LARP) and the US Department of Energy – gave invited talks. The first plenary session closed with an update on the status of HL-LHC by the project leader, CERN's Lucio Rossi, who also officially announced the new HL-LHC timeline (see figure above right). The plenary was followed by expert talks on residual dose-rate studies, layout and integration, optics and operation modes and progress on cooling, quench and assembly (together known as QXF). Akira Yamamoto of KEK presented the important results and recommendations of the recent superconducting cable review.

There were invited talks on the LHC Injectors Upgrade (LIU) by project leader Malika Meddahi from CERN, and on the outcomes of the 2nd ECFA HL-LHC Experiments Workshop held in October – an indication of the close collaboration with the experimentalists. One of the highlights of the plenaries was the status update on the Preliminary Design Report – the main deliverable of the project, which is to be published soon. There were three days of parallel sessions reviewing the progress in design and R&D in the various work packages – named in terms of activities –





A baseline for the layout of the new interaction region is one of the main results of the activity on magnets.

Clockwise from top left: The HL-LHC timeline as of 24 September 2014. A prototype Roebel cable to be used to wind a high-temperature superconductor demonstration dipole magnet. (Image credit: CERN-PHOTO-201407-151-3.) The 20-m-long electrical transmission line containing two 20 kA MgB_2 cables. (Image credit: CERN.) Collaboration members at the 4th Joint HiLumi LHC-LARP Annual Meeting. (Image credit: KEK.) Nb_3Sn coil for the 11-T dipole-model tests. (Image credit: CERN.)

both with and without EU funding.

Refined optics and layout of the high-luminosity insertions have been provided by the activity on accelerator physics and performance, in collaboration with the other work packages. This new baseline takes into account the updated design of the magnets (in particular those of the matching section), the results of the energy deposition and collimation studies, and the constraints resulting from the integration of the components in the tunnel. The work towards the definition of the specifications for the magnets and their field quality has progressed, with an emphasis on the matching section for which a first iteration based on the requirements resulting from studies of beam dynamics has been completed. The outcomes include an updated impedance model of the LHC and a preliminary estimate of the resulting intensity limits and beam–beam effects. The studies confirmed the need for low-impedance collimators. In addition, an updated set of beam parameters consistent through all of the injectors and the LHC has been defined in collaboration with the LIU team.

Progress with magnets

The main efforts of the activity on magnets for insertion regions (IRs) in the past 18 months focused on the exploration of different options for the layout of the interaction region. The main parameters of the magnet lattice, such as operational field/gradients, apertures, lengths and magnet technology, have been chosen as a result of the worldwide collaboration, including US LARP and KEK. A baseline for the layout of the new interaction region is one of the main results of this work. There is now a coherent layout, agreed with the beam dynamics, energy deposition, cooling and vacuum teams, covering the whole interaction region.

The engineering design of most of the IR magnets has now started and the first hardware tests are expected in 2015. There was also good news from the quench-protection side, which can meet all of the key requirements based on the results from tests performed on the magnets. In addition, there is a solution for cooling the inner triplet (IT) quadrupoles and the separation dipole, D1. It relies on two heat exchangers for the IT quadrupole/orbit correctors assembly, with a separate system for the D1 dipole and the high-order corrector magnets. Besides these results, considerable effort was devoted to selecting the technologies and the ▷

Old machine to validate new technology

Crab cavities have never been tested on hadron beams. So for the recently selected HL-LHC crab cavities (RFD and DQW, see main text), tests in the SPS beam are considered to be crucial. The goals are to validate the cavities with beam in terms of, for example, electric field, ramping, RF controls and impedance, and to study other parameters such as cavity transparency, RF noise, emittance growth and nonlinearities.

Long straight section 4 (LSS4) of the SPS already has a cold section, which was set up for the cold-bore experiment (COLDEX). Originally designed to measure synchrotron-radiation-induced gas release, COLDEX has become a key tool for evaluating electron-cloud effects. It mimics the cold bore and beam screen of the LHC for electron-cloud studies. Installed in the bypass line of the beam pipe, COLDEX is assembled on a moving table so that beam can pass either through the experiment during machine development runs or through the standard SPS beam pipe during normal operation. It has been running again since the SPS started up again last year after the first long shutdown, providing key information on new materials and technology to reduce or suppress severe electron-cloud effects that would otherwise be detrimental to LHC beams with 25 ns bunch spacing – as planned for Run 2.

Naturally, SPS LSS4 would be the right place to put the crab-cavity prototypes for the beam test. The goal was originally to install them during the extended year-end technical stop of 2016–2017, to validate the cavities in 2017, the year in which series construction must be launched. However, installing the cavities together with their powering and cryogenic infrastructure in an access time of 11–12 weeks is a real challenge. So at the meeting in Tsukuba, the idea of bringing forward part of the installation to 2015–2016 was discussed. However, in view of the severe electron-cloud effects that were computed in 2014 for LHC beam at high intensity, and the consequent need for a longer and deeper study to validate various solutions, COLDEX needs to run beyond 2015.

So what other options are there for testing the crab cavities? A preliminary look at possible locations for an additional cold section in the SPS led to LSS5. This would result in having two permanent "super" facilities to test equipment with proton beams. The hope is that these facilities would not only be available for testing crab cavities for the HL-LHC project, but would also provide a world facility for testing superconducting RF-accelerating structures in intense, high-energy proton beams. With the installation of adequate cryogenics and power infrastructure, a facility in LSS5 could further evolve and possibly also allow tests of beam damage and other beam effects for future superconducting magnets, for example for the Future Circular Collider study (*CERN Courier* April 2014 p16). This new idea raises many questions, but the experts are confident that these can be solved with suitable design and imagination.

design for the other magnets required in the lattice, namely the orbit correctors, the high-order correctors and the recombination dipole, D2.

Crabs and collimators

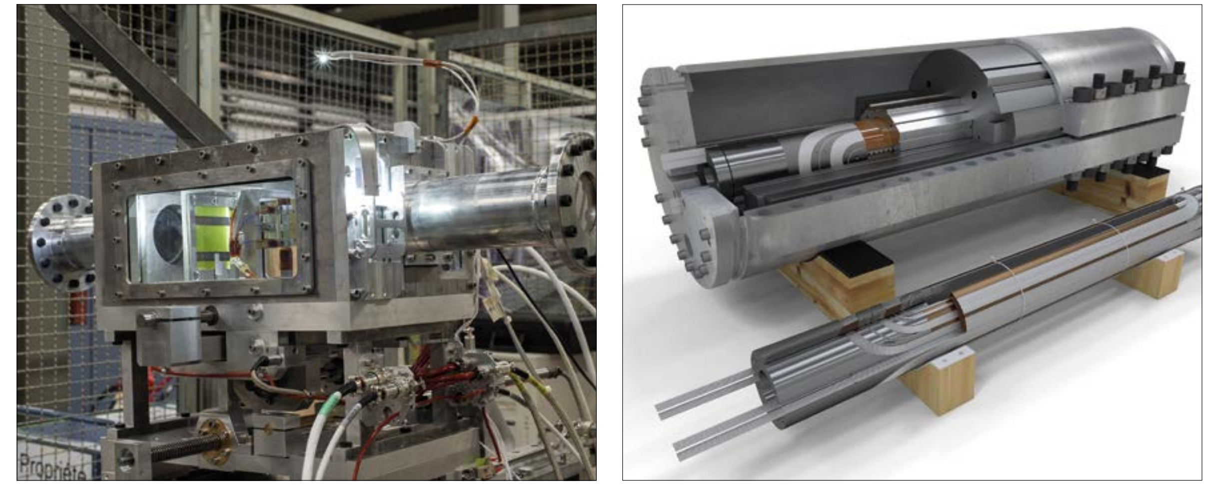
The crab-cavities activity delivered designs for three prototype crab cavities, based on four-rod, RF-dipole (RFD) and double quarter-wave (DQW) structures. They were all tested successfully against the design gradient with higher-than-expected surface resistance. Further design improvements to the initial prototypes were made to comply with the strict requirements for higher-order-mode damping, while maintaining the deflecting field performance. There was significant progress on the engineering design of the dressed cavities and the two-cavity cryomodule conceptual design for tests at CERN's Super Proton Synchrotron (SPS).

Full design studies, including thermal and mechanical analysis, were done for all three cavities, culminating in a major international design review where the three designs were assessed by a panel of independent leading superconducting RF experts. As an outcome of this review, the activity will focus the design effort for the SPS beam tests on the RFD and DQW cavities, with development of the 4-rod cavity continuing at a lower priority and not foreseen for the SPS tests. A key milestone – to freeze the cavity designs and interfaces – has also been met. In addition, a detailed road map to follow the fabrication and installation in the SPS has been prepared to meet the deadline of the extended year-end technical stop of 2016–2017.

The wrap-up talk on the IR-collimation activity also reviewed the work of related non-EU-funded work packages, namely machine protection (WP7), energy deposition and absorber co-ordination (WP10), and beam transfer and kickers (WP14). The activity has reached several significant milestones, following the recommendations of the collimation-project external review, which took place in spring 2013. Highlights include important progress towards the finalization of the layouts for the IR collimation. A solid baseline solution has been proposed for the two most challenging cleaning requirements: proton losses around the betatron-cleaning insertion and losses from ion collisions. The solution is based on new collimators – the target collimator long dispersion suppressor, or TCLD – to be integrated into the cold dispersion suppressors. Thanks to the use of shorter 11 T dipoles that will replace the existing 15-m-long dipoles, there will be sufficient space for the installation of warm collimators between two cold magnets. This collimation solution is elegant and modular because it can be applied, in principle, at any "old" dipole location. As one of the most challenging and urgent upgrades for the high-luminosity era, solid baselines for the collimation upgrade in the dispersion suppressors around IR7 and IR2 were also defined. In addition, simulations have continued for advanced collimation layouts in the matching sections of IR1 and IR5, improving significantly the cleaning of "debris" from collisions downstream around the high-luminosity experiments.

Cold powering

The cold-powering activity has seen the world-record current of 20 kA at 24 K in an electrical transmission line consisting of two 20-m-long MgB_2 superconducting cables. Another



Left: A crystal target for advanced collimation under test in CERN's HiRadMat facility. (Image credit: CERN.) Right: Computer-generated image of Fermilab's 1-m-long 11-T dipole model and a pair of CERN coils. (Image credit: Don Mitchell/Fermilab.)

achievement was with the novel design of the part of the cold-powering system that transfers the current from room temperature to the superconducting link. Following further elaboration, this was adopted as the baseline. The idea is that high-temperature superconducting (HTS) current-leads will be modular components that are connected via a flexible HTS cable to a compact cryostat, where the electrical joints between the HTS and MgB_2 parts of the superconducting link are made. Simulation studies were also made to evaluate the electromagnetic and thermal behaviour of the MgB_2 cables contained in the cold mass of the superconducting link, under static and transient conditions.

The final configuration has tens of high-current cables packed in a compact envelope to transfer a total current of about 150 kA feeding different magnet circuits. Cryogenic-flow schemes were also elaborated for the cold-powering systems at points 7, 1 and 5 on the LHC. An experimental study performed in the 20-m-long superconducting line at CERN was launched to understand quench propagation in the MgB_2 superconducting cables operated in helium gas. In addition, integration studies of the cold-powering systems in the LHC were also done, with priority given to the system at point 7.

The meeting also covered updates on other topics such as machine protection, cryogenics, vacuum and beam instrumentation. Delicate arbitration took place between the needs of crab-cavity tests in the SPS at long straight section 4 and the requirements for the continuing study and tests of electron-cloud mitigation of those working on vacuum aspects (see box).

Summaries of the EU-funded work packages closed the meeting, showing "excellent technical progress thanks to the hard and smart work of many, including senior and junior", as project leader Rossi concluded in his wrap-up talk.

Upcoming meetings will be the LARP/HiLumi LHC meeting on 11–13 May at Fermilab and the final FP7 HiLumi LHC/LARP collaboration meeting on 26–30 October at CERN. As a contribution to the UNESCO International Year of Light, special events celebrating this occasion will be organized by HL-LHC throughout the year – see cern.ch/go/light. (See also Viewpoint in this issue, p54.)

Résumé

Un avenir lumineux pour le LHC

Pour que la science continue de progresser et afin d'exploiter tout le potentiel de la machine, le LHC va devoir fonctionner à plus haute luminosité. Le projet LHC haute luminosité (HL-LHC) vise à accroître la luminosité d'un facteur de 5 à 10 au-delà de la luminosité nominale initiale en vue d'atteindre $3000\,fb^{-1}$ d'ici une dizaine d'années. Différentes activités ont été lancées pour mettre au point les technologies nécessaires pour ce relèvement de luminosité. La quatrième réunion annuelle conjointe HiLumi LHC/LARP, tenue en novembre, a permis de passer en revue les résultats et les recommandations des études effectuées en 2014.

Agnes Szeberenyi, CERN.

CERNCOURIER
Volume 55 Number 2 March 2015
IOP Publishing

Spin goes Chinese

With SPIN2014, the International Symposium on Spin Physics visited China for the first time.

The lecture hall at Peking University provided an attractive setting for many sessions. (Image credits: SPIN2014 organizers.)

The biannual series of international symposia on spin physics plays a leading role at the interface of nuclear and particle physics on one hand, and the study of spin-dependent phenomena in experiment and theory on the other. The series grew from the merger of the five-yearly symposia on polarization phenomena in nuclear reactions, first held in Basel in 1960, and the symposia on high-energy spin, which started in 1974 and had reached the 13th edition by 1998. The joint meetings began as the 14th International Symposium on Spin Physics in 2000. The 21st International Symposium on Spin Physics (SPIN2014) is the first in the series that China has hosted – taking place on the 40th anniversary of the first high-energy spin meeting at Argonne National Laboratory in 1974.

The scientific programme of the symposium series today is based on physics with photons and leptons, spin phenomena in nuclei and nuclear reactions, and new physics beyond the Standard Model. It also includes new technologies related to accelerators, storage rings, polarized targets and polarized beams, and spin physics in medicine is also included. In addition, SPIN2014 extended the topics to incorporate spin in condensed matter, quantum communication and their related applications.

Hosted by Peking University, Beijing, and supported by many renowned research institutions and universities, both inside and outside of China, SPIN2014 took place on 20–24 October 2014. Nearly 300 participants attended from more than 20 countries. With 28 plenary talks and 177 parallel talks, the symposium provided a platform to communicate new results in the field of spin physics and to reinforce academic collaborations with colleagues. It was also an important platform to advertise the academic achievements of Chinese researchers, and to strengthen the importance of Chinese involvement in spin physics. The following gives an overview of the scientific programme.

Hadrons, nucleons and symmetries

A key highlight was the excellent opening plenary talk on the spin structure of the nucleon by Xiangdong Ji of Shanghai Jiao Tong University and the University of Maryland. The quest to determine the origin of nucleon spin challenges the understanding of QCD. There is a worldwide experimental programme underway using spin observables to gain insight into this fundamental question in hadronic physics. The conference also heard more than 50 reports from experiments carried out at Brookhaven, CERN, DESY, Jefferson Lab and KEK on measurements that included inclusive lepton scattering (quark and gluon contributions), proton–proton scattering (gluon contribution, quark flavour decomposition using W-boson production), semi-inclusive deep-inelastic scattering (quark flavour decomposition, transverse-momentum distributions), deeply virtual Compton scattering (quark orbital angular momentum) and fragmentation in electron–positron collisions. There were also discussions on future possible experiments, including polarized Drell–Yan scattering, at Fermilab, the Japan Proton Accelerator Research Complex, the Nuclotron-based Ion Collider fAcility (NICA) in Dubna, and Brookhaven's Relativistic Heavy-Ion Collider (RHIC). Keh-Fei Liu of the University of Kentucky gave an overview of the exciting developments in lattice QCD in a plenary talk. This was followed by more than 20 presentations on theoretical research into the spin structure of hadrons.

The plenary programme on "Spin Physics in Nuclear Reactions and Nuclei" included a report by Andro Kacharava from the Forschungszentrum Jülich on results from the Cooler Synchrotron (COSY) on nucleon–nucleon scattering using polarization degrees of freedom to probe nuclear forces. Mohammad Ahmed of North Caroline Central University described the latest results on few-body reactions from the High Intensity Gamma-Ray Source Facility at the Triangle Universities Nuclear Laboratory, where both polarized beam and polarized ▷

The quest to determine the origin of nucleon spin challenges the understanding of QCD.

Co-chair Haiyan Gao opening the conference.

targets were employed, as well as results on Compton scattering from ^{6}Li and ^{16}O. Fifteen talks in the parallel programme were related to spin physics in nuclear reactions and nuclei.

Spin physics plays an important role in studies of fundamental symmetries and searches for new physics beyond the Standard Model of particle physics. Plenary talks included reports on the latest result on the weak charge of the proton from parity-violating electron scattering by Dave Mack of Jefferson Lab. Mike Snow of Indiana University presented recent results on hadronic parity-violating experiments such as $np \rightarrow d\gamma$, while Brad Filippone of Caltech provided an overview of the worldwide effort on searches for particle electric-dipole moments (EMDs). Frank Maas described the latest results on dark-photon searches from the University of Mainz and elsewhere. From China, Wei-Tou Ni of National Tsinghua University discussed the role of spin experiments in probing the structure and origin of gravity. Thirteen talks relating to fundamental symmetries were presented in the associated parallel sessions.

Current tools and future facilities

The methods to study spin-dependent effects are fundamental for the spin-physics community. At SPIN2014, the two main areas of interest were acceleration, storage and polarimetry of polarized beams, and sources of polarized ion and lepton beams and polarized targets. Nearly all of these disciplines formed part of the exciting plenary of Annika Vauth of DESY, who discussed the status of beam polarization and the International Linear Collider that could be built in Japan. Nearly 20 parallel talks were devoted to accelerator aspects, among them studies in the US and in China on electron–ion colliders (EICs), at JINR on the use of NICA as a polarized-ion collider, on storage rings for searches for ion EDMs, and on the new tools to be developed to meet these challenges. The operation of existing rings with polarized beams and the steady improvement of their operational parameters were also covered, with RHIC and its amazing performance as the only double-polarized ion collider built so far, and with COSY, which is famous for its stored polarized beams in the medium-energy range and the variety of internal targets.

More than a dozen parallel talks on sources and targets were presented, introduced by Dmitriy Toporkov of the Budker Institute of Nuclear Physics in his plenary on experiments with polarized targets in storage rings, in which he showed the potential of this technique. The review on polarized sources by Anatoli Zelenski of Brookhaven and other parallel talks covered a wide span of polarized beams, from high-intensity electrons for an EIC, to protons, as in H^{-} ions for RHIC, to deuterons for COSY and ^{3}He ions for eRHIC. Chris Keith of Jefferson Lab and other speakers in the parallel sessions covered solid targets polarized by dynamic nuclear polarization or by the brute-force method in several lepton-scattering experiments. Gas targets for H, D and ^{3}He atoms were also discussed.

The conference heard reports on major upgrades of spin capabilities at existing facilities. The status and plans for Jefferson Lab's 12 GeV upgrade were presented in a plenary talk by associate director Rolf Ent, and Wolfgang Lorenzon of the University of Michigan described the possibility of polarizing the Fermilab proton beam and mounting a programme of polarized Drell–Yan measurements. In Europe, the Mainz Energy-Recovering Superconducting Accelerator provides a high-intensity low-energy polarized electron facility, while COSY has embarked on a major development of new polarized proton- and deuteron-beam capabilities, motivated by experiments to look for nonzero EDMs in light nuclei.

Alexander Nagaytsev of JINR described the new accelerator NICA under construction in Dubna, together with the planned spin-physics programme, including measurements of polarized Drell–Yan and J/ψ production. In the US, the QCD community is pursuing a high-luminosity polarized EIC. This could be implemented at Brookhaven or Jefferson Lab. The concept has driven R&D in both high-intensity polarized electron guns and a polarized ^{3}He source. In the *European Physical Journal A* plenary lecture, Zein-Eddine Mezziani of Temple University gave a compelling presentation on the spin science that motivates this new machine. Physicists in China have recently become interested in a similar facility.

Further features

As a novelty, SPIN2014 included a significant programme on spintronics – low-dimensional solid-spin systems exhibiting different quantum effects that can be employed, for example, in quantum computers, metrology, information technology and more. This ambitious field of research and technology is being pursued actively at Tsinghua and Peking Universities, and many other Chinese institutes, and was presented in a public lecture (see below) as well as in parallel sessions that included 20 talks. Apart from spintronics themes, medical applications such as imaging were discussed, a highlight being the beautiful talk by Warren Warren of Duke University on "Imaging with Highly Spin-Polarized Molecules". There were also two talks on the application of polarized fuel for fusion reactors.

Besides the communication of recent results at the physics frontier, SPIN2014 also organized a lecture on popular science by Qi-Kun Xue from Tsinghua University on "Quantum Anomalous Hall Effect and Information Technology", attended by more than 100 people from Peking University, Tsinghua University, Beijing University of Posts and Telecommunications, Beihang University and others. A memorial session devoted to the memory of CERN's

The poster session presented new research results.

Michel Borghini was organized by Alan Krisch of Michigan and Akira Massike of Kyoto, highlighting Borghini's contributions to the development of solid polarized targets.

A poster session for presenting new research results included Outstanding Poster Awards, sponsored by the Hanscom endowment from Duke University. From 14 posters, three young researchers from the China Institute of Atomic Energy, Tsinghua University and the Institute of Modern Physics of the Chinese Academy of Sciences received awards. The hope is that the poster session and awards will inspire young researchers to work with passion in the area of spin physics. A reception and banquet, and a visit to the nearby Summer Palace, served to bring all of the participants together, enhancing close discussions. They will surely remember SPIN2014 as a stimulating meeting that demonstrated the beauty and vitality of the field – and look forward to the next in the series, which will take place on 26–30 September 2016 at the University of Illinois Urbana-Champaign.

● For more about the organizers and sponsors of SPIN2014, and details of the full programme, visit www.phy.pku.edu.cn/spin2014/.

Résumé

La physique du spin à l'heure chinoise

Organisée sous les auspices de l'Université de Pékin, à Beijing, et bénéficiant du soutien de nombreux instituts de recherche et universités de renom de Chine et d'ailleurs, SPIN2014 a rassemblé près de 300 participants de plus de 20 pays. À travers de nombreuses séances plénières et parallèles, le symposium a été l'occasion d'annoncer de nouveaux résultats dans le domaine de la physique du spin, et de renforcer les collaborations de recherche, mais aussi de présenter les travaux universitaires de chercheurs chinois, et de mettre en avant le rôle d'équipes chinoises dans le domaine de la physique du spin.

Haiyan Gao, Duke University and Tsinghua University, **Bo-Qiang Ma**, Peking University, co-chairs of SPIN2014, **Richard Miner**, MIT, and **Erhard Steffens**, University of Erlangen.

Faces & Places

Appointments

Masanori Yamauchi to be director-general of KEK

Masanori Yamauchi has been selected to be the next director-general of KEK – the High Energy Accelerator Research Organization in Japan – with effect from 1 April. He will succeed Atsuto Suzuki, whose third term as director-general finishes at the end of March.

Masanori is currently director of the Institute of Particle and Nuclear Studies, KEK. After studying physics at the University of Tokyo, he gained his PhD in experimental particle physics for research at the PEP-4 experiment at SLAC, which saw the first major application of a time-projection chamber (TPC) in the study of e^+e^- collisions at the PEP storage ring (*CERN Courier* January/February 2004 p40). He worked subsequently for 10 years at KEK on the TRISTAN e^+e^- collider, before joining the Belle collaboration at the KEK B-Factory in 1994 as a founding member. He served as a co-spokesperson of Belle in the years 2003–2009, and since 2010 has been a member of the Belle II collaboration at SuperKEKB.

Masanori's appointment is for three years, with the possibility of being reappointed a maximum of twice, for the same period.

Masanori Yamauchi. (Image credit: KEK.)

Awards

Vienna University of Technology honours Felicitas Pauss

On 30 October, the Vienna University of Technology awarded the degree Doctor *honoris causa* to Felicitas Pauss from ETH Zurich. The honour was bestowed in recognition of her outstanding contributions to the field of particle physics, in terms of her scientific achievements, her strong involvement in science policy making, her continuous support of the Austrian particle-physics community and her efforts to communicate the fascination of fundamental science to the general public.

In his *laudatio*, the dean of the Faculty of Physics, Gerald Badurek, highlighted among many scientific accomplishments her leading involvement in two Nobel-prize-winning discoveries, namely that of the W and Z bosons with the UA1 experiment and, more recently, the Higgs boson discovery at the LHC, where she played a pivotal role in the CMS experiment, in particular for the electromagnetic calorimeter. Her vision and policy-making skills are internationally renowned, and exemplified by the number of scientific and academic committees of which she has been a member or chair. Most notably, as head of international relations at CERN, she was key in the ongoing development of the organization in the direction of a "world laboratory". She has also been commended as a role model, and for her engagement in transmitting her enthusiasm for being a scientist to the general public.

Felicitas Pauss, centre, at the award ceremony, together with the rector, Sabine Seidler, right, and the vice-rector, Adalbert Prechtl. (Image credit: Vienna University of Technology.)

In a ceremony on 30 November, Bikash Sinha, right, was awarded the degree of DSc Honoris Causa by his alma mater, the University of Calcutta, in the presence of the chancellor, Keshari Nath Tripathi, centre, and vice-chancellor, Suranjan Das, left. With an interest in heavy-ion collisions, Sinha has been a leading figure in India's contributions to experiments at CERN's SPS, Brookhaven's RHIC and, finally, in ALICE at the LHC (CERN Courier April 2008 p38). As director of the Variable Energy Cyclotron Centre in Kolkata for 25 years, he oversaw the transition to a superconducting cyclotron. He was also director of the neighbouring Saha Institute of Nuclear Physics for 17 years. Founded in 1857, Calcutta University is the alma mater of Satyendra Nath Bose, who is remembered in the name "boson" for particles that obey Bose–Einstein statistics. (Image credit: Calcutta University.)

CELEBRATION

Scientifc Day honours Schopper's 90th

A Scientific Day took place at the Cyprus Institute in Nicosia on 24 October, to celebrate the 90th birthday of Herwig Schopper. Distinguished scientists from the international scientific community participated, together with eminent people from Cypriot society and government. The day paid tribute to Schopper's scientific achievements and also highlighted his talent for bringing people – and peoples – together.

After a welcome by Constantina Alexandrou, Costas Papanicolas started the series of talks by introducing the Cyprus Institute. Created with the vision to help transform Cyprus into a knowledge-based economy through research programmes and training in technology, it has become a key research and technology institute for Cyprus and the region. Papanicolas acknowledged and thanked Schopper for his involvement in the creation of the institute from the beginning – his roles as a founding trustee and chair of the Scientific Advisory Council were key to the development of the institute's high levels of scientific excellence.

Edouard Brézin, chair of the board of trustees, covered Schopper's many achievements in world science, across a range of nuclear and particle physics, as well as other areas of advanced scientific research. Among his early research projects was the development of the first source of polarized protons. He also became interested and contributed significantly to the evidence of parity violation in β decays, and led one of the first experiments aimed at testing time-reversal symmetry. In addition, Schopper studied neutron–proton and neutron–nuclei total cross-sections, and invented the technique of hadron calorimetry to measure the energy and direction of neutrons. Later, he worked on the development of superconducting proton linacs and particle separators.

Schopper's days at DESY – from the 1970s to the future – were the topic for DESY's former director, Albrecht Wagner. He recalled significant milestones in DESY's history since its founding in 1959, including the particle-physics programmes at the DESY, DORIS, PETRA and HERA machines. He also looked to the future with the European XFEL project – an X-ray laser laboratory for synchrotron radiation research that will continue the pioneering work at HASYLAB. The future at DESY also includes a hub for particle-physics co-ordination, support for LHC physics, enhanced Tier-2 capabilities in the Worldwide LHC Computing Grid, the International Linear Collider and the IceCube Neutrino Observatory. Schopper served as director of DESY during the years 1973–1980, and under his mandate the laboratory not only made outstanding discoveries, such as the gluon, but also prepared for new ones, for example B mixing. At the same time, DESY started to become a truly international laboratory, opening the door to collaboration with China.

Herwig Schopper, sixth from left in the front row, together with the "Science Day" participants. (Image credit: Cyprus Institute.)

Former director-general of CERN, Luciano Maiani, dealt with the directions of particle physics in the aftermath of the discovery of the Higgs boson. Somewhat paradoxically, the discovery has opened a critical period for particle physics, with the first run of the LHC providing confirmation of the Standard Model but no sign of new physics. Maiani reviewed perspectives for new physics for the second LHC run at higher energies and at future higher-energy facilities, focusing on the physics of supersymmetry and searches for composite Higgs particles.

CERN's Emmanuel Tsesmelis then described Schopper's years as the organization's director-general during 1981–1988. He also looked ahead to the high-energy frontier, in particular through the update of the European Strategy for Particle Physics in 2013. Among the elements underpinning the strategy is the importance of the European organizational model for particle physics. As director-general, Schopper promoted and strengthened this model through enlargement of CERN's member states to include Portugal and the return of Spain. Another important legacy for today – as the scale of facilities for particle physics results in increased globalization of the field – was tireless work that Schopper undertook in this respect to make the Large Electron–Positron (LEP) collider a reality. The history of LEP is indeed the history both of Schopper and of the groundwork for the LHC, with the size of the LEP tunnel being decided also in view of the future LHC.

More recently, Schopper has had a key role in the Synchrotron light for Experimental Science and Applications in the Middle East (SESAME) facility. This "third-generation" synchrotron light source – under construction in Allan, Jordan – is a co-operative venture by scientists and governments of the region. Set up on the model of CERN, it will be the region's first international research centre. Khaled Toukan, SESMAE's director, underlined both Schopper's key role in this important project as president of the SESAME Council in the years 2004–2008, and his unrelenting support of international scientific co-operation and the advancement of peace through scientific endeavour.

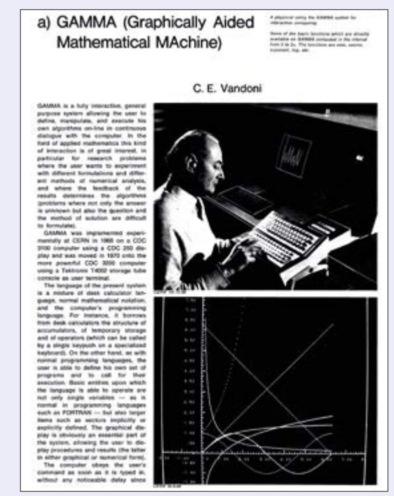
In closing, Schopper himself spoke about 70 years with physics, physicists and other people. He focused on biographical anecdotes and insights into how decisions are taken through personal experience in positions of leadership, and concluded by thanking everyone who had made the day so special and successful.

The day also included the 2014 Hubert Curien Memorial Lecture, given by Carlo Rubbia on the future of energy. He presented a broad look at the challenges facing current energy systems in the context of global warming, and spoke about innovate approaches to sustainability studies as well as specific research activities. In particular, he illustrated the potential of a methane-based society relying on innovative low-carbon technologies – such as methane cracking and the recovery of CO_2 for the production of methanol – to mitigate climate change.

CERN Courier available online 1959–2015

For more than half a century, *CERN Courier* – and until July 2005 the French edition, *Courier CERN* – has kept its readers up to date about what happens at CERN and at many other places in the world of particle physics. At the end of the 1990s, it entered the digital age, appearing as an electronic journal on the website *cerncourier.com*, in parallel to the paper version distributed wordwide, and became available more recently as a digital PDF edition.

However, for readers without access to well-provisioned scientific libraries, it became more and more difficult to get access to the back issues of *CERN Courier*/*Courier CERN*, but this has now changed. As of this year, the entire back catalogue is freely available to anyone with access to the internet. All of the issues have been digitized and the text made searchable. Furthermore, all of the pictures and plots have been extracted separately to facilitate the use of this material in conference presentations, on websites, etc. The rights for the reuse of any illustrations must be sought from the original copyright holder, which may not necessarily be CERN.



A search on "GAMMA" turns up this page – one of the topics for this issue's Archive (p17). (Image credit: CERN.)

The old volumes offer remarkable reading. From the days when *CERN Courier* was still a "house magazine", readers can find out about topics such as "What CERN is doing" (November 1959 p8), as well as recurrent issues such as "CERN staff and how we get them" (April 1960 p4). Even back then, however, the magazine contained news from other laboratories, as the first editor, Roger Anthoine, explained at the time of the magazine's 50th anniversary (*CERN Courier* July/August 2009 p23). The first edition's column on "Other people's atoms" includes items on new linacs at 40 MeV for DESY and 40 GeV for Stanford (August 1959 p6). The latter of course became famous as the SLAC linac, and is still at the heart of the Linac Coherent Light Source (see p19 this issue).

So, readers, take a few minutes to enjoy past stories and return to the new digital collection as often as you like when looking for historical pieces of information.

- For the full collection, visit cds.cern.ch/collection/CERN%20Courier%20Issues?ln=en.

Participants at the specialized school. (Image credit: Guillaume Jeanneret-Gris/CERN.)

SCHOOLS

CAS rides the plasma wake

The CERN Accelerator School (CAS) recently organized a specialized course on plasma-wake acceleration, which took place at CERN on 23–29 November.

Following a number of introductory lectures on laser and plasma physics, as well as an overview about conventional accelerators and their limitations, the course covered a large number of aspects in plasma-wake-acceleration schemes. These included creation of the plasma by high-power lasers or particle beams, description of the plasma-creation process in simulations, and characteristics of the accelerated particle beams and results from the latest achievements. Lectures about beam diagnostics, applications of plasma-accelerated beam and topical seminars completed the programme.

The course was attended by 109 students representing 26 nationalities, with most of the participants coming from European counties but also from the US, Israel, India, Korea, Russia and Ukraine. In addition to the academic programme, they also had the opportunity to take part in a typical Swiss-folklore evening and a CERN visit, both of which were appreciated highly by all who took part.

The following CAS courses are planned for 2015: Accelerators for Medical Applications, Vösendorf, 26 May–5 June; Advanced Accelerator Physics, Warsaw, 27 September–9 October; and Intensity Limitations in Particle Accelerators, CERN, 2–11 November.

● For more information, visit www.cern.ch/schools/CAS.

MEETING

The **Top at Twenty** workshop, dedicated to the celebration of 20 years since the discovery of the top quark in 1995, will take place at Fermilab on 9 April. Speakers from all experiments capable of studying the top quark – ATLAS, CMS, CDF and DZero – will present the most recent results of the top-quark studies based on Run II of the Tevatron and Run 1 of the LHC. Theoretical talks on how the top quark fits into the Standard Model and its potential extensions will be presented also. For more information, visit indico.fnal.gov/event/TopAtTwenty15.

OBITUARIES

Lowell Bollinger 1923–2014

Lowell Bollinger, a pioneer in nuclear-physics research, died on 25 September at the age of 91.

Bollinger was brought up in India and educated at Oberlin College, where he received his BA in 1943, before working as a physicist at the Aircraft Engine Research Laboratory until 1946. After World War II he attended Cornell, where he received his PhD in 1951, his thesis being on one of the earliest underground cosmic-ray measurements, observing muons 600-m deep in a salt mine.

He joined the Physics Division at Argonne National Laboratory in 1951, and during his long distinguished career played an important role in many areas of nuclear and accelerator physics. Developing a fast chopper at the CP5 reactor, he did definitive work on the properties of neutron resonances and their capture widths. He also pioneered γ-ray spectroscopy, establishing systematics in the decay of neutron resonances and the characteristics of γ-ray cascades in the de-excitation of compound nuclei.

In 1963, Bollinger became director of the Physics Division, serving for more than a decade. During this time he built up a strong contingent of research staff focused on nuclear physics – indeed, Argonne remains a major centre in nuclear physics to this day. When he stepped down as director of the division, it was to lead a small group exploring the possible applications of superconductivity to the acceleration of beams of nuclei. The result was the first successful use of superconducting radiofrequency (SRF) technology for the acceleration of sub-relativistic particles aimed at investigations of nuclear structure.

Lowell Bollinger. (Image credit: ANL.)

The extremely high "Q" of a superconducting resonator made phase and frequency control a challenge. One of the major accomplishments of Bollinger's group was development of the combined use of a slow frequency-tuning system and a fast reactance system, to stabilize against vibrations and achieve the synchronization of the RF fields necessary for precisely controlled acceleration. Another achievement was to develop a multi-stage harmonic buncher to shape the time profile of a DC beam to match the acceleration window of the linac. Bollinger's hands-on involvement in all aspects of the development, including setting up the required cryogenic system, was crucial. Under his leadership, first a prototype and then a fully funded, successful accelerator – ATLAS – were constructed. ATLAS has since evolved in its capabilities to become a major international user facility for nuclear-structure research.

The pioneering work of Bollinger, Ken Shepard, and their co-workers was followed by a number of other nuclear-physics facilities using SRF for accelerating sub-relativistic particles – at Florida State, Kansas State, Stony Brook, the University of Washington, and TRIUMF in North America, as well as in Europe, Asia and Australia. This demonstration of using SRF technology for accelerating sub-relativistic particles continues to have a major influence on research facilities. It is being applied currently in the Facility for Rare Isotope Beams, a major new facility for nuclear physics under construction at Michigan State University, and a number of similar projects worldwide. It is also the basis of the high-intensity linac injector project at Fermilab.

In recognition of Bollinger's achievements, the American Physical Society awarded him the 1986 Tom W Bonner Prize for "his contributions to and leadership in the development of the superconducting linear accelerator for the production of high-quality ion beams, a new technology that broadens the base for nuclear structure research".

● *His friends and former colleagues at Argonne.*

Anselm Citron 1923–2014

Anselm Citron, one of CERN's pioneers and an enthusiastic scholar and internationally renowned researcher, passed away on 8 December at the age of 91.

He contributed considerably to establishing the research programme of the Institut für Experimentelle Kernphysik (IEKP) at Karlsruhe University – now the Karlsruhe Institute of Technology (KIT) – where he continued to take an active part in matters until shortly before he died. His scientific achievements lie in fundamental and seminal work in the area of accelerator technology, which in many cases still finds applications today, and in his contributions to physics with exotic atoms and hadrons, including the intriguing observation of a glueball candidate. He was a member of the renowned German Academy of Sciences Leopoldina.

Citron was born on 27 March 1923 in Stettin (then in Germany, today Szczecin in Poland). In 1934 his family moved to Freiburg, where he went to high school, until, to escape the persecution of people with Jewish roots, he was sent to the Netherlands. He obtained his matriculation in Zutphen, followed by a short period at a technical high school. He was then transferred to the Eastern Front during the last stages of the Second World War, and returned in 1945 to Freiburg. There, he studied physics at the institute of Wolfgang Gentner, obtaining his PhD for investigations of large air showers in the mountains of the Schwarzwald. In 1952 he married Renate Lais, and together they raised five daughters.

After obtaining his PhD, Citron started as a postdoc at Cavendish Laboratory, Cambridge, in 1952, to take part in research on accelerator physics. A year later, he went to the newly founded CERN as one of the first 12 staff physicists. There he contributed ▷

to the construction of the 28 GeV Proton Synchrotron (PS), where he was responsible for the high-frequency power system and beam shielding. After this, he moved to work on the CERN Synchrocyclotron (SC), where he constructed the first muon channel with strong focusing.

In 1964, Citron was sent to Brookhaven National Laboratory to work in the machine division. Several offers of professorships in Marburg, Munich and Karlsruhe ensued, and he decided to go to Karlsruhe University in 1965, joining and expanding the IEKP founded by Herwig Schopper. Citron had a professorial chair in Karlsruhe until 1991, and at the same time was director of one of the three institutes for nuclear physics. Together, the institutions under Citron had a staff of 280. After restructuring, IEKP and the Institut für Kernphysik continue to exist at the recently founded KIT, focusing on elementary particle physics and astroparticle physics.

During his tenure, Citron's research projects included the following highlights: the development of high-frequency superconducting cavities, which are still being used in contemporary accelerators; studies at the light-ion accelerator KALIF at Karlsruhe; the development of a 1 MW gyrotron for plasma heating inside fusion reactors; and the development of electron cooling at the Low Energy Antiproton Ring (LEAR) at CERN.

Anselm Citron, front, looks at a quadrupole for the muon beam at the SC with, left to right, Bengt Hedin, Marinus van Gulik and Pierre Lapostolle. (Image credit: CERN-GE-6104308.)

In parallel, he initiated research efforts at international laboratories, CERN and PSI, with noteworthy highlights including: precise measurements with muonic, pionic and antiprotonic atoms; pion-induced reactions with light nuclei at CERN and PSI; meson spectroscopy with antiprotons with the Crystal Barrel experiment at LEAR, for which the crystal calorimeter was constructed in Karlsruhe; and observation of the $f_0(1500)$, a glueball candidate.

Citron was also a dedicated teacher. He supervised many PhD and habilitation theses. As dean of the Physics Faculty, he laid the foundation for the contemporary research profile in Karlsruhe. He was particularly dedicated to the needs of junior staff members, which was also evident in his strong engagement with students supported by the Deutsche Studienstiftung (an elite student programme).

We remember Anselm Citron dearly, as a highly esteemed colleague who was greatly appreciating and respected. Not only an internationally renowned scientist who paved the way in modern particle-physics research, he was also a valuable mentor to the members of the IEKP. He acted as an example for many of his colleagues, particularly in his enduring engagement on behalf of the persecuted.

Our memory of him will always remain.

● *Helmut Koch, Thomas Müller, Herwig Schopper, IEKP.*

Hans Hofer 1934–2014

Hans Hofer, emeritus professor at ETH Zurich and experimental particle physicist of international renown, passed away on 28 September.

Born on 17 October 1934 in Zurich, Hofer studied physics at the University of Bern, where he obtained a PhD in 1965 under the supervision of George Sudarshan. After a stay at the University of Chicago, where he collaborated with Valentine Telegdi, and his return to the University of Bern, in 1973 he was appointed associate professor of experimental high-energy physics at the Federal Institute of Technology (ETH) in Zurich, and promoted to full professor in 1981. He was chair of the physics department for several years, as well as head of the former laboratories of nuclear and high-energy physics, in the case of the latter until his retirement in 2001.

Hofer's main research interests were in the fields of nuclear and particle physics. His dynamic personality and his engagement earned him an excellent reputation, both at

Hans Hofer. (Image credit: Rita Vonesch.)

the national and international level. Under his leadership, his group contributed to the construction of the MARK J detector at PETRA, DESY, and then took a leading role in the L3 experiment at CERN's Large Electron–Positron collider. He also made important contributions to the Alpha Magnetic Spectrometer (AMS) experiment, particularly to the magnet and system integration. In addition, he played a pivotal role in implementing the electromagnetic crystal calorimeter and the superconducting-magnet system of the CMS experiment at the LHC, as well as the superconducting cables for the ATLAS experiment.

His excellent leadership qualities and diplomatic skills were essential to many of these achievements, and helped in the formation of international collaborations including physicists and engineers from Eastern Europe and China. Besides the successful implementation of many projects, Hofer's total devotion to particle physics is reflected in a publication list comprising more than 400 journal articles, and recognized through many awards, honorary titles and visiting professorships.

● *His ETH colleagues.*

Valery Zagrebaev 1950–2015

Valery Ivanovich Zagrebaev, deputy director of the Flerov Laboratory of Nuclear Reactions (FLNR) at the Joint Institute for Nuclear Research (JINR), passed away suddenly on 17 January, aged 64.

Valery Zagrebaev graduated with a degree in physics from Leningrad State University, where he subsequently defended his PhD and habilitation theses. He then began his academic career in the Department of Theoretical Physics at Chuvash State University, where he worked for more than 25 years, holding positions as an assistant, then associate professor and, finally, professor. In 1997, he was appointed as a senior researcher at JINR FLNR. Two years later, he founded and became head of the laboratory group of theoretical and computational physics, and in 2007 he became the deputy director of JINR FLNR, a position that he held up to his death. During his career, he published more than 190 scientific articles in top journals, both in Russia and abroad, and was awarded JINR prizes in 1997, 2002 and 2007, in recognition of his outstanding scientific achievements.

With academic interests interwoven intricately with research in nuclear-reaction dynamics at low and intermediate energies, Zagrebaev is known for his fundamental work in various fields of nuclear physics that played a key role in establishing and

Valery Zagrebaev. (Image credit: JINR.)

developing many areas of further research. For example, his calculations served as a basis for a series of experiments carried out in leading laboratories worldwide. He also initiated the development of a unique network of knowledge on low-energy nuclear physics, which continues to expand today. A co-discoverer of the superheavy elements with atomic numbers 113, 114, 115, 116 and 118, synthesized during the past few years at JINR FLNR, most recently in 2011 he initiated and led work on the development of a state-of-the-art set-up for the selective laser ionization and separation of nuclear-reaction products. He is also recognized internationally for his expertise in heavy-ion physics, and made important contributions to the development of quasi-classical approaches for the description of a range of phenomena occurring in heavy-ion collisions.

Zagrebaev paid great attention to the training of academic staff and was involved in academic work for many years. Graduates defended PhD and habilitation theses under his guidance. In 2003, the Department of Nuclear Physics at Dubna State University was established under his leadership and with his direct involvement. The department's graduates have a range of employment opportunities, and are rated by employers as highly skilled and proficient. This is also reflected by the large majority of the graduates who went on to work successfully at JINR laboratories.

A many-sided man of great depth who contributed enormously to the development of fundamental science, Zagrebaev was more than an outstanding scientist. We are mourning the loss of a good friend, great academician and wonderful colleague, who gave freely of his time, advice and expertise. He will stay in our hearts forever, and will be remembered as an extremely thoughtful scientist and dedicated mentor.

● *His colleagues, friends, students, and the FLNR staff.*

New products

FLIR Systems is offering the A6700sc for science-grade thermal imaging. Featuring a highly sensitive 640 × 512 pixel resolution InSb detector, the A6700sc produces temperature-calibrated IR imagery. Designed for electronics inspections, medical thermography, manufacturing monitoring, and non-destructive testing, the camera is ideal for high-speed thermal events and fast-moving targets. For further information, tel +32 3665 5100, e-mail research@flir.com or visit http://flir.com/cs/emea/en/view/?id=63708.

Maxon Motor presents another miniaturized OEM plug-in module as an addition to the ESCON servo controller family. The high-performance four-quadrant PWM servo motor controller is designed to command permanent-magnet-activated brushed DC motors and brushless DC motors (EC motors) by using Hall sensors up to 48 W continuous output and 144 W peak output. The drift-free, dynamic speed behaviour enables speeds up to 150,000 rpm. For more details, tel +41 41 666 1565, e-mail marketing@maxonmotor.com or visit www.maxonmotor.com.

MKS Instruments, Inc. has introduced the 902B Absolute Piezo vacuum transducer, which integrates a MEMS-based piezo sensor with a sealed, stainless-steel 316 diaphragm and integrated electronics to provide seamless, gas-independent vacuum-pressure measurement between 0.1 and 1000 torr. It features up to three setpoint relays, a high bakeout temperature of 100 °C, and a reduced process cycle time. For more details, see www.mksinst.com/news/NewsDetail.aspx?id=525.

Narda Safety Test Solutions has developed a new generation of RF analysers, the NRA RX. These 19" rack-mount devices analyse RF signals up to 6 GHz in the frequency and time domains. They can yield spectra comprised of up to 600,000 frequency points with time resolutions as fine as around 30 ns. The demodulation function makes it possible to hear FM, AM, USB, LSB and CW signals using external headphones. For more details, e-mail info.narda-de@L-3com.com or visit www.narda-sts.com.

XP Power has announced the GSP500 series of 500 W AC–DC power supplies. Occupying a 4 × 6" footprint, these single-output forced-air-cooled units can continuously deliver the full output power across a temperature range of –40 to +50 °C, and up to 70 °C with derating. The supply requires just 12 CFM of forced air cooling, and can also provide an output power of up to 180 W with convection cooling only. For further information, visit www.xppower.com/EN/100714/GSP500-Series.

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.

IFIN-HH

Senior and Junior Researchers, Postdoctoral research assistants, PhD students, Engineers, Physicists and Technicians at Extreme Light Infrastructure – Nuclear Physics (ELI-NP)

eli Nuclear Physics

Extreme Light Infrastructure – Nuclear Physics (ELI-NP) will be a new Center for Scientific Research to be built by the National Institute of Physics and Nuclear Engineering (IFIN-HH) in Bucharest-Magurele, Romania.

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

- A very high intensity laser beams from two 10 PW lasers;
- A very intense, brilliant γ beam, very low bandwidth, with Eγ > 19 MeV, which is obtained by incoherent Compton back scattering of a laser light off an intense electron beam (Ee > 700 MeV) produced by a warm linac.

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

Senior and Junior Researchers, Postdoctoral research assistants, PhD students, Engineers/Physicists (particle accelerators, mechanics, optics), Engineers (physics, laser, electronic, electrical, electrotechnical, instrumentation and control) and Technicians.

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

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

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

Fully-funded PhD studentships

at the Cockcroft Institute of Accelerator Science and Technology

The Cockcroft Institute – a collaboration between academia, national laboratories, and industry based in the north west of England – brings together the best particle accelerator scientists, engineers, educators and industrialists to conceive, design, construct and use particle accelerators at all scales and lead the UK's participation in flagship international experiments.

Students will join an internationally leading education program with 40+ PhD students at the Cockcroft Institute. Students will be placed in one of the partner universities (Lancaster, Liverpool or Manchester) in either Physics or Engineering departments, depending on the applicant's aptitude, preference and suitability to the posts.

PhD places are currently available at the Cockcroft Institute in:
- RF Science and Engineering
- Particle Tracking and Beam Dynamics
- Mathematical Physics
- Beam diagnostics and instrumentation
- Photonics and Metamaterials
- Laser applications in accelerators
- Antimatter and Dark Matter research
- Current and Future Particle Colliders (inc. LHC)
- Next generation light source facilities

More details and application forms can be found at:
http://www.cockcroft.ac.uk/education/informationPhd.htm
Queries can be sent to Dr G. Burt.
Email: graeme.burt@cockcroft.ac.uk

Prospective students should forward a CV and supporting materials to: Janis Davidson,
Email: janis.davidson@stfc.ac.uk
Closing date for applications: 27th February, 2015

MANCHESTER 1824 The University of Manchester   LANCASTER UNIVERSITY   UNIVERSITY OF LIVERPOOL   Science & Technology Facilities Council   The Cockcroft Institute of Accelerator Science and Technology

PAUL SCHERRER INSTITUT

PSI

The Paul Scherrer Institute PSI is the largest research centre for natural and engineering sciences within Switzerland. We perform cutting-edge research in the fields of matter and materials, energy and environment and human health. By performing fundamental and applied research, we work on sustainable solutions for major challenges facing society, science and economy. PSI is committed to the training of future generations. Therefore about one quarter of our staff are post-docs, post-graduates or apprentices. Altogether PSI employs 1900 people.

For the use at the beamlines of the Swiss Light Source (SLS) - one of the most advanced radiation sources worldwide – and for use at future X-ray free electron laser (XFEL) facilities the Detector Group develops one- and two dimensional high speed solid state detectors.

In this respect, the SLS Detector Group is seeking a

Physicist

Detector Development Swiss Light Source

Your tasks

- Development and characterization of analogue and single photon counting systems (hardware and software) for use at synchrotrons and future XFEL facilities
- Improvement of currently existing systems
- Support of the detector systems and participation in x-ray experiments

Your profile
You should have a PhD in physics preferably in the field of detector development and longtime experience in detector development for synchrotrons. You have good knowledge of analogue and digital electronics and sensors for solid state detectors. Experience in C/C++ programming under linux, FPGA development using VHDL and experience in synchrotron radiation instrumentation would be appreciated.

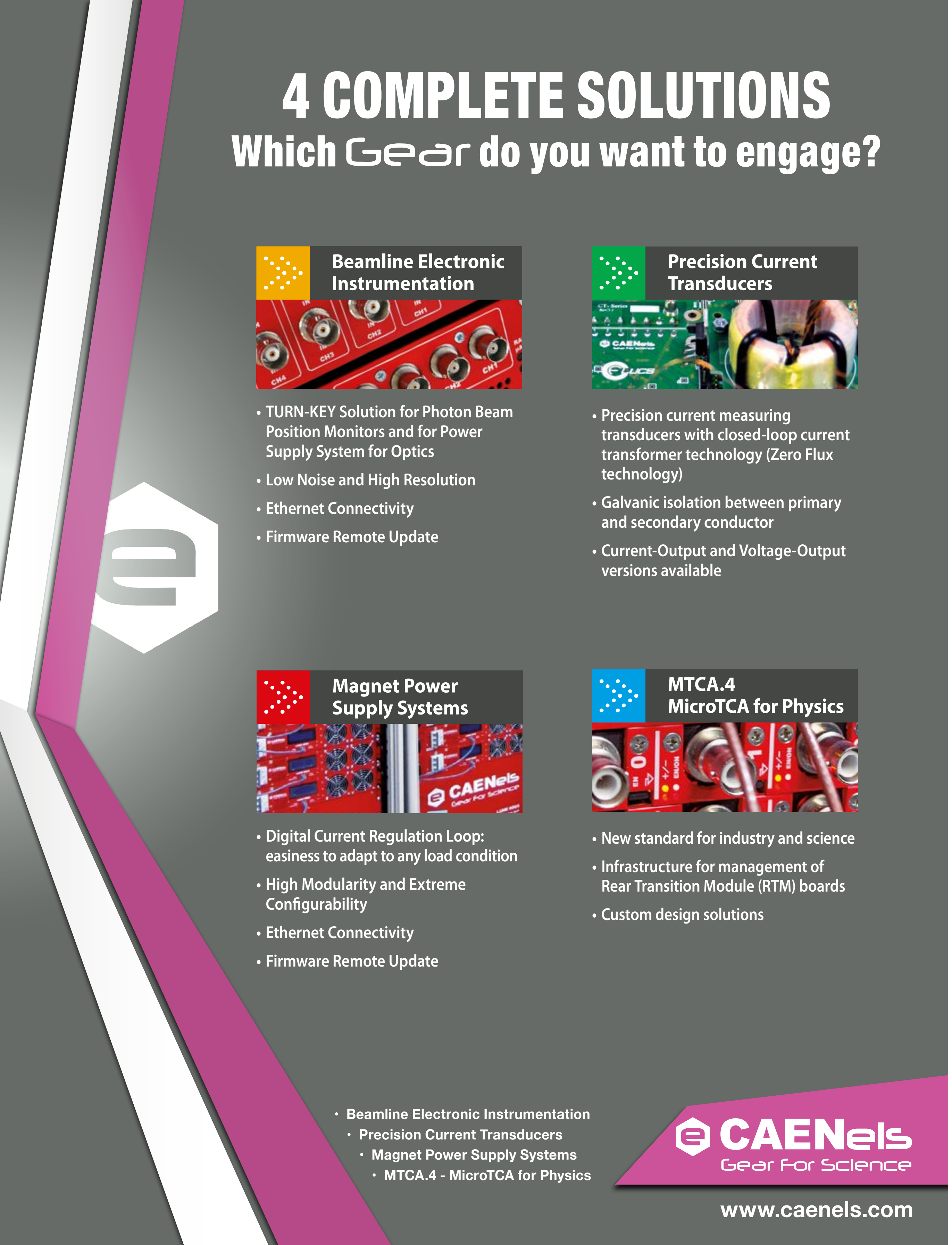
You will work as a teamplayer in a stimulating international environment, giving you excellent opportunities for new initiatives and independent research.

We offer
Our institution is based on an interdisciplinary, innovative and dynamic collaboration. You will profit from a systematic training on the job, in addition to personal development possibilities and our pronounced vocational training culture. If you wish to optimally combine work and family life or other personal interests, we are able to support you with our modern employment conditions and the on-site infrastructure.

For further information please contact Dr Bernd Schmitt, phone +41 56 310 23 14.

Please submit your application online (including list of publications and addresses of referees) for the position as a Physicist (index no. 6114-00).

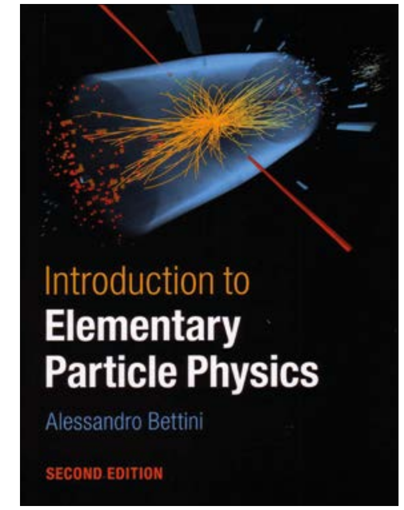
Paul Scherrer Institute, Human Resources Management, Elke Baumann, 5232 Villigen PSI, Switzerland
www.psi.ch



Bookshelf

Introduction to Elementary Particle Physics (2nd edition)

By Alessandro Bettini
Cambridge University Press
Hardback: £40 $75
Also available as an e-book, and at the CERN bookshop



The second edition of Alessandro Bettini's *Introduction to Elementary Particle Physics* appeared on my doorstep just in time for me to plan my next teaching of the class for beginning graduate students. I liked the first edition very much, and used it for my classes (*CERN Courier* May 2009 p43). I like the second edition even better.

First, the level is not overburdened with mathematics, while still introducing enough theory to make meaningful homework assignments. Inspection of the 10 chapter titles – beginning with "Preliminary Notions" of kinematics and the passage of radiation through matter, and ending with the mixing and oscillation of "Neutrinos" – shows that it is clearly written by a knowledgeable experimentalist. The organization illustrates the critical interplay between experiment and theory, but leaves the reader with no doubts that physics is an experimental science.

In the first version, I already liked the presentation of the core material such as the quantum numbers of the pion and their measurement, as well as the more sophisticated presentation of material such as the Lamb shift and the resulting development of quantum electrodynamics. Fortunately, the best of this material has also propagated into the second edition, not always the case even in famous physics texts such as those by Jackson and by Halliday and Resnick, where at least to me, the first editions are better than what followed.

Bettini weaves in a good amount of history of the pivotal discoveries that shaped the Standard Model. Beginning students were not even born when the LHC was designed, and their parents were toddlers when the W and Z bosons were discovered. I was on a bus tour at a recent physics meeting in Europe, when a young postdoc asked me what I had worked on in the past. When I told him UA1, he asked "What's that?" I was speechless, as were the more senior colleagues around us who overheard our conversation. Bettini gives a must-read, whole and balanced introduction to particle physics, appropriate for a first course.

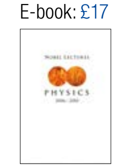
A companion website from Cambridge University Press has some nice slides of plots and figures. I generally do not like to lecture from my laptop, but sometimes data are essential to the presentation, so this is a real time saver. There is also a new solutions manual for all of the end-of-chapter problems – available only to instructors. I like many of these problems, and will use a mix of them together with my own. Best of all, for the current version, there are some timely additions, most notably the discovery of the Higgs boson and an expanded chapter on neutrino oscillations. I will need to supplement this material with the latest measurements, but I am happy to do that because it reminds me that although progress at the frontier of knowledge is painfully slow, it is not zero. Let us hope that Run 2 at the LHC will necessitate the writing of a third edition of this wonderful book.

● *James W Rohlf, Boston University.*

Books received

Nobel Lectures in Physics (2006–2010)

By Lars Brink (ed.)
World Scientific
Hardback: £51
Paperback: £22
E-book: £17



This volume is a collection of lectures delivered by the Nobel prizewinners in physics, together with their biographies and the presentation speeches by Nobel Committee members, for the years 2006–2010. The lectures provide detailed explanations of the phenomena for which the laureates were awarded the Nobel prize. The volume includes John Mather and George Smoot, honoured "for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation", as well as Yoichiro Nambu "for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics", and Makoto Kobayashi and Toshihide Maskawa "for the discovery of the origin of the broken symmetry, which predicts the existence of at least three families of quarks in nature".

Physics of Long-Range Interacting Systems

By A Campa, T Dauxois, D Fanelli and S Ruffo
Oxford University Press
Hardback: £55 $94.95
Also available as an e-book

This book deals with an important class of many-body systems: those where the interaction potential decays slowly for large inter-particle distances and, in particular, systems where the decay is slower than the inverse inter-particle distance raised to the dimension of the embedding space. Gravitational and Coulomb interactions are the most prominent examples, although long-range interactions are more common than thought previously. Intended for Master's and PhD students, the book tries to acquaint the reader with the subject gradually. The first two parts describe the theoretical and computational instruments needed to study both equilibrium and dynamical properties of systems subject to long-range forces. The third part is devoted to applications to the most relevant examples of long-range systems.

Dark Energy

By Miao Li, Xiao-Dong Li, Shuang Wang and Yi Wang
World Scientific
Hardback: £56
E-book: £42

The first volume in the Peking University–World Scientific Advance Physics Series, this book introduces the current state of research on dark energy. The first part deals with preliminary knowledge, including general relativity, modern cosmology, etc. The second part reviews major theoretical ideas and models of dark energy, and the third part reviews some observational and numerical work. It will be useful for graduate students and researchers who are interested in dark energy.

Inside Story

Circles of light: a physicist's tale

Thinker or artisan? **Lalit Sehgal** on the link between his career in physics and a tailor he saw long ago in Lahore.

Lalit Sehgal. (Image credit: Anand Sehgal.)

When I was four years old, my grandfather, who was a respected citizen of Lahore, came to our home in his horse-drawn carriage to take me along on a drive through the city. He was known to be a person of temper, so I decided not to say or do anything that might risk his ire. The drive proceeded in complete silence, but I was aware that he was observing me intently. At the end, when we returned to his spacious house, he announced to the whole family: "This young man is going to be a philosopher."

There were peals of laughter from all sides. Not knowing what the word "philosopher" meant, I hung my head in shame. A relative, seeing me crestfallen, took me aside and explained: "A philosopher is someone who thinks a lot. Your grandfather probably noticed that you were absorbed in your own thoughts." "But why did they laugh?" I asked. She said: "People assume that a person who spends too much time thinking, instead of doing something practical, will never earn enough to support himself." I had received my first lesson of life. Too much thinking is not good, and is likely to leave you poor.

Some days later, I accompanied my parents to Anarkali, a popular shopping area and meeting point for Lahore residents, after sundown. I happened to be standing next to a tailor's shop. A man seated in the doorway was working assiduously with needle and coloured thread, doing embroidery, and between stitches his hand executed a circular arc. The thimble that he wore flashed during each circular movement, reflecting the light of a lamp in the porch. As dusk turned to darkness, the tailor's face and body receded into the shadows. The only sign of his presence was the periodic flash of his thimble. The flashes appeared to merge into a circle of light, suspended in air against the dark background. It was a beautiful sight.

When I next visited my grandfather's house, I hastened to tell everyone that I had decided on my future occupation: I would be a tailor. To my surprise the statement evoked as much hilarity as on the previous occasion. Somebody remarked that a tailor's job was that of a "Karigar" (a craftsman or artisan), who worked with his hands and did not have much education, and that I should be aspiring to something higher. I protested that I had seen a tailor doing embroidery and found his work interesting. In reply, someone cautioned me that a tailor did not earn much money. It began to appear that regardless of whether I chose to be a thinker or an artisan, my future would be one of penury.

Fortunately, my parents gave me freedom to find my own way in life. I studied physics and entered a career of research and teaching. Today, in the tranquillity of retirement, I find myself recalling that childhood encounter in my grandfather's house 70 years ago. My grandfather had prophesied that I would be a philosopher. He was not far off the mark. My PhD certificate says "...Doctor of Philosophy in the field of Physics...".

My relatives had expressed apprehension that by choosing to be a thinker or artisan, I would end up in a job that was low in esteem as well as in income. It turned out that the field I chose was elementary-particle phenomenology. It allowed me to combine my propensity for thinking with the more prosaic task of analysing data and performing calculations using the theoretical tools of particle physics. In this respect, my occupation combined the traits of a thinker with those of an artisan.

Did the work bring me fame and fortune? A modicum of recognition, perhaps, but certainly no great wealth. The main reward was the joy of working with scientists, and sharing in the exhilaration of search and discovery. Was the work I did held in esteem? Here I have to be guarded in my reply. The field of elementary-particle physics tends to divide itself into groups with varying ideas about the important issues, priorities and ultimate goals. To put it crassly, some people believe that their task is to try to read the mind of God, who is a thinker. This group is convinced that the truth will be found in mathematical equations. Others believe that God is an artisan, whose blueprint will be discovered in the careful observation of the phenomena of nature. The two groups regard each other with polite tolerance, at best, and studied indifference, at worst. To the best of my judgement, the people I care for did appreciate my work.

Finally, I return to the "circle of light" that captivated me at the tailor's shop. Years later, I had a similar sense of awe when, looking down into a valley after a shower of rain, I saw a magnificent set of rainbows, both primary and secondary, against a clear blue sky. At that time I had learned enough physics to know that a rainbow was caused by the refraction and reflection of light in raindrops. A similar phenomenon that impressed me, one winter night, was a ring around the Moon, which, I learned later, was caused by ice crystals in the upper atmosphere. And finally, once I was immersed in the fast-moving world of particle physics, an image that never failed to enthral me was of the rings of light created by charged particles in a Cherenkov detector, such as in the Super-Kamiokande experiment.

As Richard Feynman once remarked, the fact that a mysterious phenomenon can be explained in physical terms does not take away from its beauty and allure. Even today, the sight of a rainbow brings to my mind an imaginary weaver, weaving a pattern with coloured threads, while the rays of the sun dance off the thimble on his moving hand.

● *Lalit M Sehgal, Aachen.*

Viewpoint

Seeing is believing

Lucio Rossi reflects on how particle accelerators extend our sense of sight.

Lucio Rossi in high resolution at CERN. (Image credit: CERN-HI-0806018-05.)

INTERNATIONAL YEAR OF LIGHT 2015

Seeing has always been a trigger for curiosity – the desire to know reality – and light is a means for bridging reality with our minds. It is not the only means, but probably the most important. Sight conveys the most information, the most detail about the world around us. Think, for example, of the richness of detail in today's high-definition (HD) or 3D images. Now, to remind us of light's importance and how useful it is in our lives, the UN has declared 2015 as the International Year of Light.

From Euclid, who first put down the principles of geometric optics in 300 BC, to Alhazen, whose first real theory of light and sight around 1000 AD was so influential in Europe, to Francesco Maurolico who in the 16th century developed a modern theory of sight and the functioning of the eyes – light and sight have long fascinated scientists. Indeed, light is fundamentally linked to the birth of modern science. In 1609–1610, Galileo Galilei was able to perfect the lens and telescope, making the first modern scientific instrument. The "canone occhiale" or "spectacles cannon" – the words at the root of the Italian for telescope – allowed him to see "things never seen beforehand", as he wrote in his "instant book" *Sidereus Nuncius*. Thanks to an instrument based on light, he was able to discover the moons of Jupiter and make the Empyrean Heaven a place where change happens, and therefore worthy of investigation by physicists.

Later in the 17th century, Francesco Grimaldi first observed diffraction – soon formalized by Christiaan Huygens in a complete physics theory – and in 1873 Ernst Abbe showed that this limits the detail of what we can see. The resolution of our vision depends on the wavelength of the light or any other wave used for detection, such as sound waves, as in bats, or electromagnetic waves of different wavelengths. So, if we use millimetre-range infrared waves, the image is inevitably less well resolved than with submicrometre visible light. That is why our vision is so good and we can appreciate the splendour of HD images.

For more than a century, physicists have been able to see with finer wavelength "light" – for example, X-rays with wavelengths 100–1000 times shorter – and today, being able to "see" atoms at the nanometre scale, daily life is invaded by "nanotechnology". Nevertheless, we can peer down to much smaller scales. Just 90 years ago, Louis de Broglie put forward the unimaginable idea that a particle can behave like a wave, with a wavelength inversely proportional to its momentum. This completed the particle–wave duality initiated by Albert Einstein in his *annus mirabilis*, when he realized that waves behave like particles and introduced the concept of light quanta, the photons.

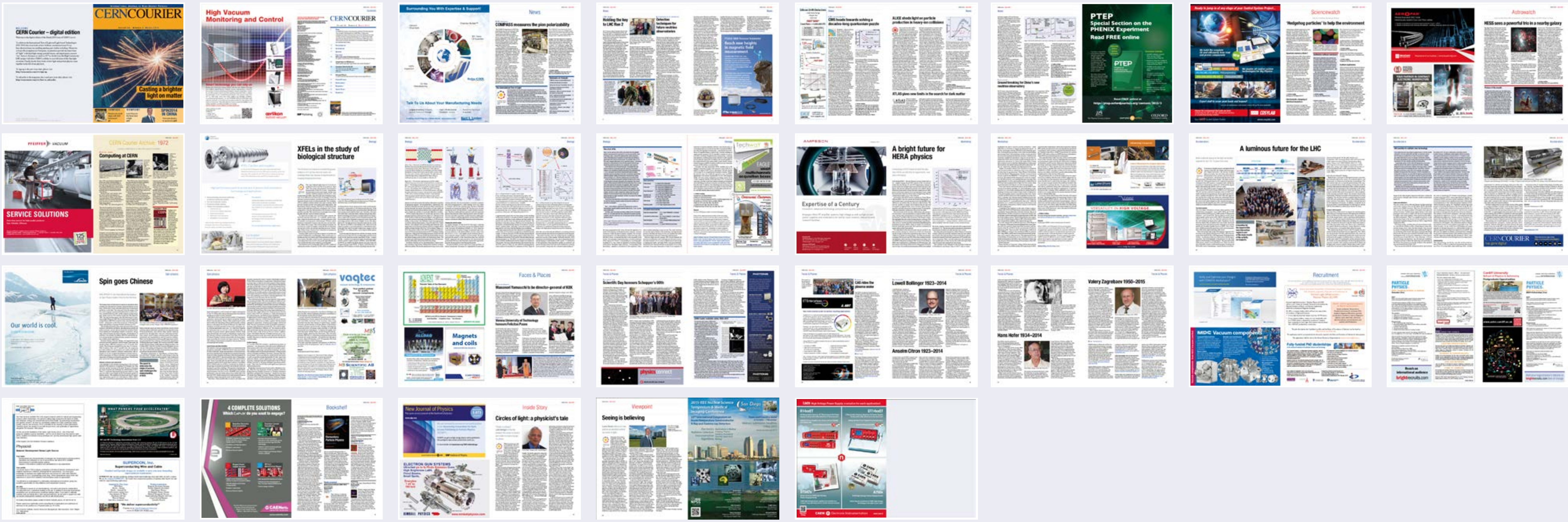
In this way, particle accelerators can generate the finest "light". The cyclotrons and synchrotrons of the 1950s and 1960s were capable of illuminating entities such as protons, but were limited by diffraction in the femtometre range. Each new, more powerful accelerator joined the race for the finest light, allowing the best resolving power. Most recently, with the LHC, the simple relation $\lambda = h/p$ tells us that at 1 TeV (the average collision energy of a quark–quark interaction) we can resolve the attometre, or 10^{-18} m, scale. However, thanks to higher energy in some collisions and to sophisticated experimental techniques, the LHC has shown that quarks are point-like at the level of 5×10^{-20} m, or 50 zeptometres.

But light is only a means, a bridge between reality and our minds, where the image is formed and vision occurs. Indeed the light generated by the LHC would be useless without "eyes" – the LHC detectors that collect the collision events to record the detail illuminated by the light. As with the eyes, the collected information is then transmitted to the mind for image formation. At the LHC, the computers, the physics theory, the brains of the experimentalists and theoretical physicists – all of these form the "mind" where the wonderful images of, for example, the Higgs boson, are formed and, finally, known. Exactly as with sight, some signals (most of them, in fact) are first treated "unconsciously" (by the trigger) and only a selected part is treated consciously on a longer time scale.

Now the LHC is restarting and we will be able to generate light almost as twice as fine, thanks to the 13 TeV collision energy. Moreover, the High-Luminosity LHC project is already on the starting blocks to be ready 10 years from now (p28). Why high luminosity? Just as in a room where we might ask for more light to investigate finer details and measure the properties of objects more precisely, with the LHC we are planning to increase luminosity by a factor of five (instantaneous) or 10 (integrated) to make more precise measurements and so extend our sight, i.e., the physics reach of the collider and the detectors.

With our accelerators, detectors, computing facilities, physics analysis and theory, we really do reproduce the act of sight, generating the finest light and therefore perceiving a reality that is unimaginable to our normal senses: the frontier of the infinitely small.

● *Lucio Rossi, CERN, is leader of the High-Luminosity LHC project.*



CERNCOURIER

Volume 55 Number 2 March 2015

Contents