WELCOME

CERN Courier – digital edition

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

HERA – the world's first, and so far only, electron–proton collider – ran at DESY from 1992 to 2007, yielding a fascinating view of the innermost structure of the proton. Now, using their data from HERA, the H1 and ZEUS collaborations have combined forces to produce the most detailed picture yet, which in turn provides valuable input for physics studies at the new high-energy frontier that the LHC is just beginning to explore. At the same time, other collaborations, such as RD51 at CERN, are working on the development of detectors for the upgrade in intensity at the LHC, while others are beginning to think about reaching still higher energies – and the innovative process this will entail.

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

CERN COURIER

VOLUME 55 NUMBER 8 OCTOBER 2015

Inside the proton: HERA's legacy

DETECTORS

RD51 collaboration stimulates MPGD development **p26**

ACCELERATORS

Could an inventive methodology help to guide innovation? **p23**

EPS-HEP 2015

News from the Vienna conference **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

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 Jiang Ya'ou, Library, Institute of High Energy Physics,
PO Box 918, Beijing 100049, People's Republic of China
E-mail: jiangyo@ihep.ac.cn
Germany Antje Brandes, DESY, Notkestr. 85, 22607 Hamburg, Germany
E-mail: desypr@desy.de
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 CERN

CERN COURIER

VOLUME 55 NUMBER 8 OCTOBER 2015

5 **NEWS**
• *Zeroing in on Higgs boson properties* • *So, farewell then* • *STAR tracker snares heavy flavours* • *Positrons catch a wave at SLAC* • *ALICE in Vienna: from antinuclei to quark–gluon plasma* • *CMS observes simultaneous production of top quarks and Z bosons* • *Searches for new phenomena with LHC Run-2* • *ALICE goes forward with the ridge in pPb collisions* • *LHCb improves trigger in Run 2*

13 **SCIENCEWATCH**

15 **ASTROWATCH**

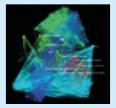
17 **ARCHIVE**

FEATURES

19 **The most precise picture of the proton**
H1 and ZEUS release their definitive paper on deep-inelastic scattering.

23 **Inventing our future accelerator**
Could an inventive methodology help to guide the innovate process?

26 **RD51 and the rise of micro-pattern gas detectors**
The RD51 collaboration has provided important stimulus for growth in the development of MPGDs.



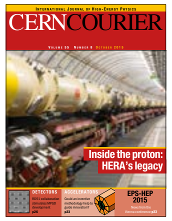
33 **Vienna hosts a high-energy particle waltz**
A report from the first major summer conference on particle physics.

37 **FACES&PLACES**

43 **RECRUITMENT**

49 **BOOKSHELF**

50 **VIEWPOINT**



On the cover: HERA – the world's first and so far only electron–proton collider – ran at DESY from 1992 to 2007. Using data collected there, the H1 and ZEUS collaborations have combined forces to publish the most precise results to date on the innermost structure and behaviour of the proton (p19). (Image credit: DESY.)

News

CERN

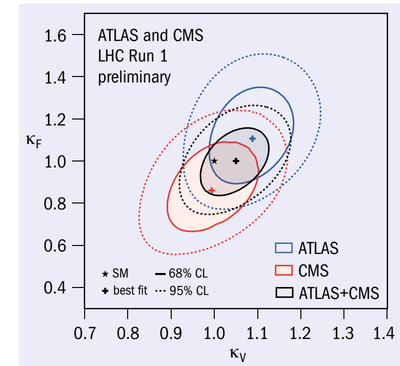
Zeroing in on Higgs boson properties

As Run 2 at the LHC gains momentum, a combined analysis of data sets from Run 1 by the ATLAS and CMS collaborations has provided the sharpest picture yet on the Higgs boson properties (ATLAS 2015, CMS 2015).Three years after the announcement in July 2012 of the discovery of a new boson, the two collaborations are closing the books on measurements of Higgs properties by performing a combined Run 1 analysis, which includes data collected in 2011 and 2012 at centre-of-mass energies of 7 and 8 TeV, respectively. This analysis follows hot on the heels of the combined measurement of the Higgs boson mass, $m_H = 125.09\pm0.24$ GeV, published in May by ATLAS and CMS (ATLAS and CMS 2015).

The new results are the culmination of one and a half years of joint work by the ATLAS and CMS collaborators involved in the activities of the LHC Higgs Combination Group. For this combined analysis, some of the original measurements dating back to 2013 were updated to account for the latest predictions from the Standard Model. A comprehensive review of all of the experimental systematic and theoretical uncertainties was also conducted to account properly for correlations. The analysis presented technical challenges, because the fits involve more than 4200 parameters that represent systematic uncertainties. The improvements that were made to overcome these challenges will now make their way into data-analysis tools, such as ROOT, that are widely used by the high-energy particle-physics community.

The results of the combination present a picture that is consistent with the individual results. The combined signal yield relative to the Standard Model expectation is measured to be 1.09±0.11, and the combination of the two experiments leads to an observation of the $H\to\tau^+\tau^-$ decay at the level of about 5.5σ – the first observation of the direct decay of the Higgs boson to fermions. Thanks to the combined power of the data sets from ATLAS and CMS, the analysis yields unprecedented measurements of the properties of the Higgs boson, with a precision that enables the search for physics beyond the Standard Model in possible deviations of the measurements from the model's predictions. The figure shows clearly the increased precision obtained when combining the ATLAS and CMS analyses.

The combined analysis is performed for many benchmark models that the LHC Higgs Cross-Section Working Group proposed, so as to be able to explore the various different effects of physics models that go beyond the Standard Model. As Run 2 gains momentum, the two collaborations are looking forward to reaping the benefits of the increase in centre-of-mass energy to 13 TeV, which will make some of the most interesting processes, such as the production of Higgs bosons in association with top quarks, more accessible than ever. However, even with the first results from Run 2, this set of combined results from 7 and 8 TeV collisions in Run 1 will continue to provide the sharpest picture of the Higgs boson's properties for some time to come.



Results of the analyses by the individual experiments (coloured) and of the combined analysis (black). The fit to the data is performed using coupling modification factors κ_V and κ_F that scale, respectively, the electroweak symmetry-breaking-related coupling to the weak bosons and the Yukawa-related coupling to all fermions, with respect to the Standard Model prediction. The black star at $(\kappa_V, \kappa_F) = (1, 1)$ denotes the Standard Model expectation. In this fit, the total width is assumed to scale with the κ values and no allowance is made for invisible or undetected decay modes.

Further reading

ATLAS and CMS Collaborations 2015 *Phys. Rev. Lett.* **114** 191803.
ATLAS Collaboration 2015 ATLAS-CONF-2015-044.
CMS Collaboration 2015 CMS-HIG-15-002.

So, farewell then...

After nearly 13 years as editor of *CERN Courier*, I am stepping down as I head off into retirement. I would like to thank the many contributors and also the team at IOP Publishing who bring such a professional standard to the magazine. Most importantly, I must thank the enthusiastic readers for their continued support, and ask everyone to join me in welcoming the new editor, Antonella Del Rosso. *Christine Sutton, CERN.*

Sommaire en français

Zoom sur les propriétés du boson de Higgs	5
Au revoir	5
Le trajectographe de STAR piège les saveurs lourdes	6
Les positons surfent sur la vague au SLAC	6
ALICE à Vienne : des antinoyaux au plasma quark-gluon	7
CMS observe la production simultanée de quarks top et de bosons Z	8
Exploitation 2 du LHC : à la recherche de nouveaux phénomènes	8
ALICE progresse avec les corrélations à grand angle dans les collisions pPb	10
LHCb améliore son déclenchement pour l'exploitation 2	10
Prédateur et proie : la pupille comme assistance	13
L'Univers s'essouffle	15

Heavy ions

STAR tracker snares heavy flavours

Heavy quarks are important probes of the quark–gluon plasma that is produced when relativistic heavy ions collide. Because of a mass effect, it has been argued that heavy quarks lose less energy through gluon radiation than light quarks as they traverse the medium. However, studying heavy quarks in a particle-dense environment is challenging. Moreover, the physics interest is in bulk behaviour of charm quarks, so it is important to study charmed hadron production over the full range of momentum. At low momenta, multiple scattering is very important, and this places strict constraints on the amount of material in the detector.

The STAR Heavy Flavour Tracker (HFT) was built to meet these challenges. Installed in the STAR detector at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory early last year, it took data during the 2014 and 2015 running periods. It was specifically designed and constructed to allow for the direct topological reconstruction of heavy-flavour decay vertices such as the D^0 (decay distance $c\tau$ around 120 μm), by tracking the decay particles through four layers of silicon detectors to extend the STAR physics programme to include fully reconstructed charmed hadrons.

To do this, the tracker incorporated a number of novel features. First, in addition to the two outermost layers of standard-technology silicon strips and pad sensors, the innermost two layers of the HFT – the pixel (PXL) detector (figure 1) – are constructed using monolithic active-pixel sensors (MAPS). This is the first large-scale use at a collider experiment of MAPS technology, which integrates the silicon of the detector and the signal processing on a single silicon die. Second, its novel design, with a low-mass carbon-fibre support structure, aluminum conductor read-out cables (instead of copper) and air cooling (instead of water) gives the PXL a sleek footprint with a very low radiation length – 0.4% per layer – to minimize multiple Coulomb scattering. These features give the detector, which was conceived and built by the Relativistic Nuclear Collisions group at the Lawrence Berkeley National Laboratory (LBNL), excellent pointing capabilities, with a resolution for its distance of closest approach of only 40 μm for 750 MeV/*c* kaons.

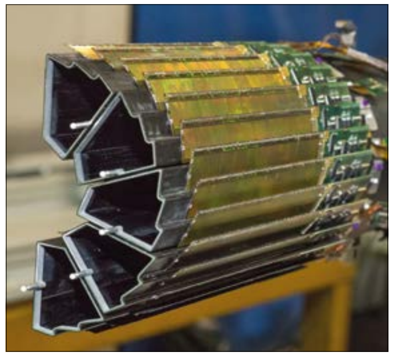


Fig. 1. One half of the PXL detector, showing 50 μm-thick MAPS sensors mounted on their carbon-fibre supports. The complete detector consists of 400 MAPS sensors arranged into two layers at radii of 2.8 and 8 cm from the beamline. The outer layer is visible here. (Image credit: Berkeley Lab/Roy Kaltschmidt.)

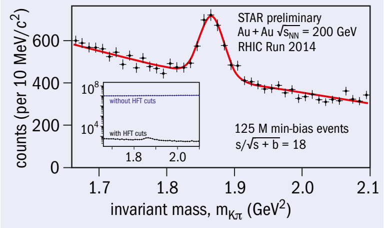


Fig. 2. The $D^0 \rightarrow K\pi$ invariant-mass peak from direct topological reconstruction of the separated vertices, using the HFT for 10% of the data taken during the 2014 beam run at RHIC. The inset compares the peak without (blue) and with (black) the use of HFT information to select separated vertices.

In addition, the detector-support mechanics are designed to allow for very fast insertion and detector replacement. The PXL detector can be inserted, cabled and working in 12 hours. This allows for quick changes if the detector suffers radiation damage.

The MAPS chips were developed by the microelectronics group at the Institut Pluridisciplinaire Hubert Curien in Strasbourg, in collaboration with LBNL, and are the result of a 10 year development process. The sensor design is highly optimized for the RHIC environment. A single sensor features 890,000 pixels, each measuring 20.7 μm × 20.7 μm. The detector integration time is 186 μs, allowing the detector to function at RHIC with a very low occupancy. The fast read-out is achieved with binary output using column-level discriminators and on-chip zero-suppression/data-compression circuitry. The detector's initial performance is in line with expectations: figure 2 shows an invariant $D^0 \rightarrow K^-\pi^+$ (and conjugate) mass peak, shown at the recent Quark Matter 2015 conference.

Plasma acceleration

Positrons catch a wave at SLAC

In a study reported in *Nature*, a team working at the Facility for Advanced Accelerator Experimental Tests (FACET) at SLAC has shown that the high electric-field gradients possible in plasma can be harnessed to accelerate positrons, just as well as they can for electrons.

In 2014, an experiment at FACET, which uses the first 2 km of the famous SLAC linac, was able to demonstrate plasma-wakefield acceleration of electrons, with both a high gradient and a high energy-transfer efficiency – a crucial combination that had not previously been achieved (*CERN Courier* January/February 2015 p9). However, for positrons, plasma-wakefield acceleration is much more challenging, and it was thought that no matter where a trailing positron bunch was placed in a wake, it would lose its compact, focused shape or even slow down.

In the new study, the team demonstrated a new regime for plasma-wakefield acceleration where particles in the front of a single positron bunch transfer their energy to a substantial number of those in the rear of the same bunch by exciting a wakefield in the plasma. In the process, the accelerating field is altered – "self-loaded" – so that in the tests about a billion positrons gained 5 GeV in energy with a narrow energy spread over a distance of just 1.3 m. Moreover, the positrons extract about 30 per cent of the wake's energy and form a spectrally distinct bunch with a root-mean-square energy spread as low as 1.8%.

This ability to transfer energy efficiently from the front to the rear within a single positron bunch makes the scheme highly attractive as an energy booster for a future electron–positron collider.

Further reading

S Corde *et al.* 2015 *Nature* **524** 442.

CERN Courier October 2015
News

EPS-HEP 2015

ALICE in Vienna: from antinuclei to quark–gluon plasma

The 2015 edition of the European Physical Society Conference on High Energy Physics (EPS-HEP 2015), which took place in Vienna in July (p33), provided an opportunity for the ALICE collaboration to present the latest results from analysis of data from Run 1 of the LHC. While many of the presentations centred on the properties of the quark–gluon plasma (QGP) as produced in the collisions of heavy ions, there was also an interesting glimpse of other kinds of physics that ALICE can address.

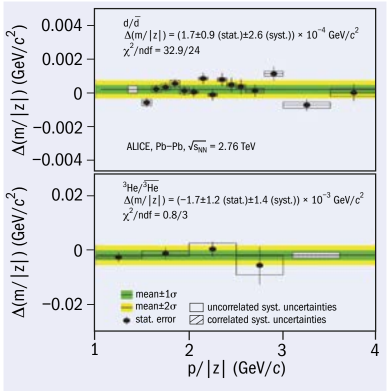
Once in a while in the heavy-ion collisions, a few protons and neutrons are created close enough in phase space such that they coalesce into a nucleus. The heavier the nucleus (the larger the number of nucleons), the lower the probability that it is created, but about once in 10 thousand events, for example, a ^{3}He nucleus can be created and detected within ALICE's tracking and particle-identification set-up. Moreover, the lead–ion collisions at the LHC also provide a copious source of antiparticles, such that nuclei and the corresponding antinuclei are produced at nearly equal rates.

This allows ALICE to make a detailed comparison of the properties of the nuclei and antinuclei that are most abundantly produced. At EPS-HEP 2015, the collaboration presented a new limit on the conservation in nucleon–nucleon interactions of CPT symmetry – the fundamental symmetry that implies that all of the laws of physics are the same under the simultaneous reversal of charges (charge conjugation, C), reflection of spatial co-ordinates (parity transformation, P) and time inversion (T). The new test of CPT invariance was extracted from measurements of the mass-to-electric-charge ratios of the deuteron/antideuteron and the ^{3}He/$\overline{^3\text{He}}$ nuclei. The combined results of the difference of the mass-over-charge ratio for each pair of the nucleus/antinucleus species allowed the extraction of differences in their relative binding energies. The measurements, published in *Nature Physics*, confirm CPT invariance to an unprecedented precision in the sector of light nuclei (ALICE Collaboration 2015).

The strongly interacting hot and dense matter, the QGP, produced in heavy-ion collisions is characterized by the smallest ratio of sheer viscosity to entropy density of all known materials – a substance that flows almost as a perfect liquid. This QGP is a system of quarks and gluons where the mean free path is very short – a so-called strongly coupled system. A parton traversing such a medium, even a highly energetic one, is exposed to the medium and loses part of its energy. The new measurements by ALICE presented at EPS-HEP 2015 indicate that the heavier charm and beauty quarks also lose a significant part of their energy in the dense QGP. For relatively low quark momenta, the interaction with the bulk of the partons in the medium may follow exclusively through elastic scatterings. For high-energy quarks, a number of soft gluons can be radiated, carrying a fraction of quark energy into the medium. These processes are a QCD analogue of phenomena known from QED: the physics of a parton traversing a droplet of QGP resembles the scenario of an electrically charged particle traversing ordinary matter.

In other measurements, the ALICE collaboration has compared data on the production of D mesons (containing a charm quark) with data from CMS on non-prompt J/ψ mesons (the decay products of heavier mesons containing a beauty quark). The comparison shows that the heavier the quark, the less energy it loses inside the medium. Indeed, this was one of the most striking predictions of theoretical models describing strongly coupled QCD matter – the plasma is less opaque to heavy quarks as compared to light quarks and gluons. So, these new measurements at last provide the first confirmation of these predictions.

The nature of the interactions between the heavy quarks and the medium can also be deduced from the azimuthal asymmetry of the production of heavy-flavour hadrons: the magnitude of the asymmetry is proportional to the collective flow of the medium. Measurements of the asymmetry presented by ALICE confirm that the heavy quarks participate in the collective flow of QGP. These results are critical to establishing the focus of future theoretical work on the transport properties of the plasma, while from the experimental point of view, the ALICE collaboration is looking forward to the improved precision from the measurements in LHC Run 2.



The d/$\bar{d}$ (top) and ^{3}He/$\overline{^3\text{He}}$ (bottom) mass-over-charge ratio difference measurements, as a function of the particle rigidity.

The droplet of QGP produced in heavy-ion collisions constantly expands, and lasts at most about 10 fm/*c* (30×10^{-24} s). After that time, the temperature drops below the critical temperature (about 155 MeV) and the energy density falls below a critical density of about 0.5 GeV/fm^3. At that point, the distances between the quarks become large and, owing to the nature of the strong force, the partons are re-confined/combined into colour-neutral hadrons. Following this hadronization process, the system becomes a gas of hadrons and, while the gas is still hot, the hadrons may still interact. The most useful messengers from this phase of the collision are the short-lived hadronic resonances. At the conference, ALICE presented extensive studies of the short-lived mesons and baryons. Their production rates provide sensitive information on the strength of the hadron–hadron interactions, and thus are a vital source for understanding the properties of the hadron gas. Knowing the equation-of-state of the hadron gas allows the genuine QGP signals to be unravelled in greater detail.

Finally, ALICE presented signatures of collective particle production in an extended pseudorapidity range in proton–lead collisions (p10). Such collective behaviour, known from heavy-ion collisions, was not initially expected for the smaller proton–lead system. The new measurement provides qualitatively new constraints to theoretical models attempting to explain the novel phenomena.

Further reading

ALICE Collaboration 2015 *Nature Physics* doi:10.1038/nphys3432.

CERNCOURIER
Volume 55 Number 8 October 2015
IOP Publishing

LHC EXPERIMENTS

CMS observes simultaneous production of top quarks and Z bosons

In an improved analysis of 8 TeV collision events at the LHC, the CMS experiment has made the first observation of a top quark–antiquark pair together with a Z boson, $t\bar{t}Z$, as well as the most precise cross-section measurements of $t\bar{t}Z$ and $t\bar{t}W$ to date.

Since the top quark was discovered 20 years ago, its mass, width and other properties have been measured with great precision. However, only recently have experiments been able to study directly the top quark's interactions with the electroweak bosons. Its coupling to the W boson has been tightly constrained using single top events in proton–antiproton collisions at Fermilab's Tevatron and proton–proton collisions at the LHC. Direct measurements of the top quark's couplings to the photon (γ) and the Z or Higgs boson are currently most feasible in LHC collisions that produce a $t\bar{t}$ pair and a coupled boson: $t\bar{t}\gamma$, $t\bar{t}Z$ and $t\bar{t}H$. However, studying these processes (and the related $t\bar{t}W$) is challenging because their expected production rates are hundreds of times smaller than the $t\bar{t}$ cross-section.

The CMS and ATLAS experiments at CERN have previously observed $t\bar{t}\gamma$, found evidence for $t\bar{t}Z$, and conducted searches for $t\bar{t}W$ and $t\bar{t}H$ in 7 and 8 TeV proton–proton collisions. Deviations from the predicted cross-sections could hint at non-Standard Model physics such as anomalous top-quark-boson couplings or new particles decaying into multiple charged leptons and bottom quarks.

The decays $t\bar{t}W$ and $t\bar{t}Z$ both produce two b quarks, and are most easily distinguished from $t\bar{t}$, WZ, and ZZ backgrounds when they produce two to four charged leptons and up to four additional quarks. However, signal events can be identified even more precisely when the reconstructed leptons and quarks are matched to particular top, W or Z decays. Leptons of the same flavour and opposite charge, with an invariant mass near 91 GeV, are assigned to Z decays. The remaining leptons and quarks are compared with top and W decays using the charge and b-quark identification of single objects, together with the combined mass of multiple objects. Every possible permutation of objects matched to decays is tested, and the best matching is taken as the reconstruction of the entire $t\bar{t}W$ or $t\bar{t}Z$ event. Background events with fewer top quarks or W or Z bosons are typically worse matches to $t\bar{t}W$ and $t\bar{t}Z$ than signal events.

The figure shows the best match score in events with three charged leptons and four reconstructed quarks in data, along with estimates of $t\bar{t}Z$, WZ and $t\bar{t}$, as well as $t\bar{t}$ and single Z with a non-prompt lepton from quark decay. The hashed area indicates the 68% uncertainty in the signal-plus-background prediction. The matching scores are combined with quark and lepton momenta and other distinguishing variables in so-called boosted decision trees (BDTs),

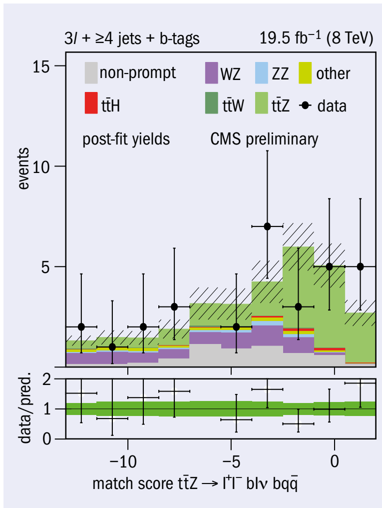


Fig. 1. Distribution of $t\bar{t}Z$ match scores with estimated signal and background yields.

which separate signal from background events. The BDTs are used to compare data events with signal and background models, and so estimate the number of signal events contained in the data. This estimate makes it possible to measure the cross-sections.

The $t\bar{t}W$ cross-section is measured in events with two same-charge leptons or three leptons, and is found to be 382^{+117}_{-102} fb, somewhat larger than the 203^{+20}_{-22} fb predicted by the Standard Model. This higher-than-expected value is driven by an excess of signal-like data events with two same-charge leptons. The data overall exclude the zero-signal hypothesis with a significance of 4.8σ. Events with two opposite-charge leptons, three leptons, or four leptons are used in the $t\bar{t}Z$ search. The measured $t\bar{t}Z$ cross-section is 242^{+65}_{-55} fb, quite close to the Standard Model prediction of 206^{+19}_{-24} fb. The zero-signal hypothesis is rejected with a significance of 6.4σ, making this measurement the first observation of the $t\bar{t}Z$ process.

The measured cross-sections are also used to place the most stringent limits to date on models of new physics employing any of four different dimension-six operators, which would affect the rates of $t\bar{t}W$ or $t\bar{t}Z$ production. Further studies in 13 TeV collisions should provide an even more detailed picture of these interesting processes and may reveal the first hints of new physics at the LHC.

Further reading

CMS Collaboration 2015 CMS-TOP-14-021.

Searches for new phenomena with LHC Run-2

After demonstrating a good understanding of the detector and observing most of the Standard Model particles using the first data of LHC Run 2 collected in July (*CERN Courier* September 2015 p8), the ATLAS collaboration is now stepping into the unknown, open to the possibility that dimensions beyond the familiar four could make themselves known through the appearance of microscopic black holes.

Relative to the other fundamental forces, gravity is weak. In particular, why is the natural energy scale of quantum gravity, the Planck mass M_{Pl}, roughly 17 orders of magnitude larger than the scales of electroweak interactions? One exciting solution to this so-called hierachy problem exists in "brane" models, where the particles of the Standard Model are mainly confined to a three-plus-one-dimensional brane and gravity acts in the full space of the "bulk". As gravity escapes into the hypothesized extra dimensions, it therefore "appears" weak in the known four-dimensional world.

With enough large, additional dimensions, the effective Planck mass, M_D, is reduced to a scale where quantum gravitational effects become important within the energy range of the LHC. Theory suggests that microscopic black holes will form more readily in this higher-dimensional universe. With the increase of the centre-of-mass energy to 13 TeV at the start of Run 2, the early collisions could already produce signs of these systems.

If produced by the LHC, a black hole with a mass near M_D – a quantum black hole – will decay faster than it can thermalize, predominately producing a pair of particles with high transverse momentum (p_T). Such decays would appear as a localized excess in the dijet mass distribution (figure 1). This signature is also consistent with theories that predict parton scattering via the exchange of a black hole – so-called gravitational scattering.

A black hole with a mass well above M_D will behave as a classical thermal state and decay through Hawking emission to a relatively large number of high-p_T particles. The frequency at which Standard Model particles are expected to be emitted is proportional to the number of charge, spin, flavour and colour states available. ATLAS can therefore perform a robust search for a broad excess in the scalar sum of jet p_T (H_T) in high-multiplicity events (figure 2), or in similar final states that include a lepton. The requirement of a lepton (electron or muon) helps to reduce the large multijet background.

Even though the reach of these analyses extends beyond the previous limits, they have so far revealed no evidence for black holes or any of the other signatures to which they are potentially sensitive. Run 2 is just underway and with more luminosity to come, this is only the beginning.

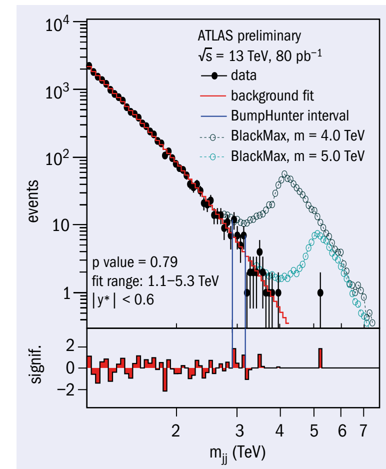


Fig. 1. The dijet mass distribution (filled points) for selected events, together with predictions from BlackMax for two quantum-black-hole signals, normalized to the predicted cross-section. The bottom panel shows the bin-by-bin significance of the difference between data and fit, considering statistical uncertainties only.

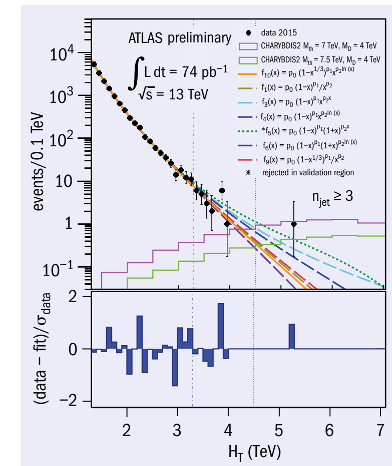


Fig. 2. Scalar sum of jet transverse momenta (H_T) in high-multiplicity events fitted by the baseline function (solid line) and six alternatives (dashed lines). Examples of simulated signals are also shown. The bottom panel shows the bin-by-bin significance of the difference between the data and the fit, where the fit prediction is taken from the baseline function.

Further reading

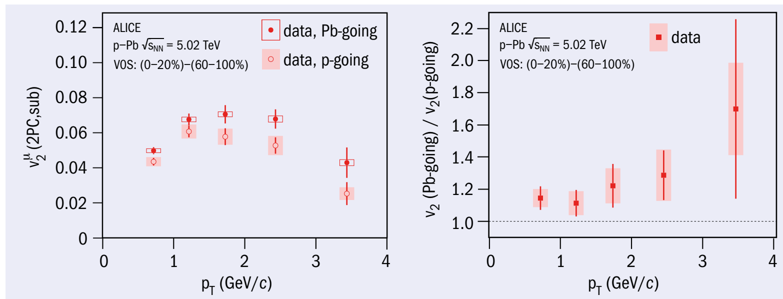
ATLAS-CONF-2015-042.
ATLAS-CONF-2015-043.
ATLAS-CONF-2015-046.

ALICE goes forward with the ridge in pPb collisions

One of the hottest debates at the LHC is the potential emergence of collective effects in proton–lead (pPb) collisions, prompted by the discovery of double ridge structures in angular correlations of charged particles (*CERN Courier* March 2013 p9), and the dependence of the azimuthal asymmetry, characterized by its second Fourier coefficient v_2, on particle mass (*CERN Courier* September 2013 p10). The experimental findings in pPb are qualitatively the same as those in PbPb collisions, and they are usually interpreted as hydrodynamic signatures of a strongly coupled, nearly perfect quantum liquid. However, QCD calculations, which invoke the colour-glass condensate (CGC) formalism for the gluon content of a high-energy nucleus in the saturation regime, can also describe several features of the data.

Thus, one of the key questions to answer is, whether the ridge is a result of final-state effects, driven by the density of produced particles, or of initial-state effects, driven by the gluon density at low-x. In the former case, v_2 could be expected to be larger in the Pb-going direction, while it would be larger the p-going direction in the latter case.

The ALICE collaboration has recently completed a measurement to address this question in analysis of pPb collisions at a nucleon–nucleon centre-of-mass energy of 5.02 TeV. Muons reconstructed in the muon spectrometer at forward (p-going) and backward (Pb-going) rapidities



The v_2^μ coefficients from the p-going and Pb-going directions, left, and their ratio, right.

$(2.5 < |\eta| < 4.0)$ were correlated with associated charged particles reconstructed in the central $(|\eta| < 1.0)$ tracking detectors. In high-multiplicity events, this revealed a pronounced near-side ridge at forward- and backward-going rapidities, ranging over about five units in $\Delta\eta$, similar to the case of two-particle angular correlations at mid-rapidity. An almost symmetric double ridge structure emerged when, as in previous analyses, jet-like correlations from low-multiplicity events were subtracted.

The v_2 for muons, v_2^μ, in high-multiplicity events was obtained by dividing out the v_2 of charged particles measured at mid-rapidity from the second-order two-particle Fourier coefficient, under the assumption that it factorizes into a product of muon v_2 and charged-particle v_2. The v_2^μ coefficients were found to have a similar dependence on transverse momentum (p_T) in p-going and Pb-going directions, with the Pb-going coefficients larger by about 16±6%, more or less independent of p_T within the uncertainties of the measurement. The dominant contribution to the uncertainty arose from the correction for jet-like correlations affecting the extraction of v_2.

The results add further support to the hydrodynamic picture, and are in qualitative agreement with model calculations incorporating final-state effects. At high p_T (> 2 GeV/*c*), the measurement is sensitive to a contribution from heavy-flavour decays, and hence may be used to constrain the v_2 of D mesons from calculations.

● **Further reading**

ALICE Collaboration 2015 arXiv:1506.08032 [nucl-ex].

LHCb improves trigger in Run 2

LHCb has significantly improved the trigger for the experiment during Run 2 of the LHC. The detector is now calibrated in real time, allowing the best possible event reconstruction in the trigger, with the same performance as the Run 2 offline reconstruction. The improved trigger allows event selection at a higher rate and with better information than in Run 1, providing a significant advantage in the hunt for new physics in Run 2.

The trigger consists of two stages: a hardware trigger that reduces the 40 MHz bunch-crossing rate to 1 MHz, and two high-level software triggers, HLT1 and HLT2 (figure 1). In HLT1, a quick reconstruction is performed before further event selection. Here, dedicated inclusive triggers for heavy-flavour physics use multivariate approaches. HLT1 also selects an inclusive muon sample, and exclusive lines select specific decays. This trigger typically takes 35 ms/event and writes out events at about 150 kHz.

In Run 1, 20% of events were deferred and processed with the HLT between fills. For Run 2, all events that pass HLT1 are deferred while a real-time alignment is run, so minimizing the time spent using sub-optimal conditions. The spatial alignments of the vertex detector – the VELO – and the tracker systems are evaluated in a few minutes at the beginning of each fill. The VELO is reinserted for stable collisions in each fill, so the alignment could vary from one fill to another; figure 2 shows the variation for the first fills of Run 2. In addition, the calibration

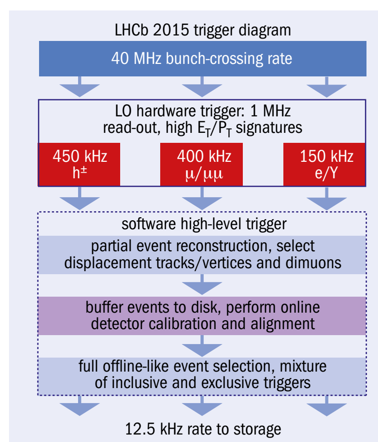


Fig. 1. The LHCb trigger structure for Run 2.

of the Cherenkov detectors and the outer tracker are evaluated for each run. The quality of the calibration allows the offline performance, including the offline track reconstruction, to be replicated in the trigger, thus reducing systematic uncertainties in LHCb's results.

The second stage of the software trigger, HLT2, now writes out events for offline storage at about 12.5 kHz (compared to 5 kHz in Run 1). There are nearly 400 trigger lines. Beauty decays are typically found using multivariate analysis of displaced vertices. There is also an inclusive trigger for D* decays, and many lines for specific decays. Events containing leptons with a significant transverse momentum are also selected.

A new trigger stream – the "turbo" stream – allows candidates to be written out without further processing. Raw event data are not stored for these candidates, reducing disk usage. All of this enables a very quick data analysis. LHCb has already used data from this stream for a preliminary measurement of the J/ψ cross-section in $\sqrt{s}$ = 13 TeV collisions (*CERN Courier* September 2015 p11).

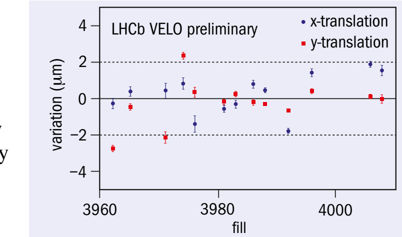
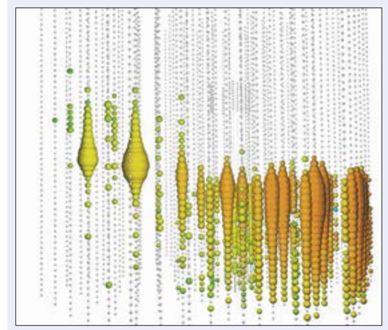


Fig. 2. The variation in the x and y translation of the VELO alignment in the first fills of Run 2.



This is an event view of the highest energy neutrino detected so far by the IceCube experiment based at the South Pole (CERN Courier *December 2014 p30). Each sphere is one optical sensor; the coloured spheres show those that observed light from this event. The sizes show how many photons each module observed, while the colour gives some idea of the arrival time of the first photon, from red (earliest) to blue (latest). It is easy to see that the neutrino is going slightly upward (by about 11.5°), so the muon cannot be from a cosmic-ray air shower; it must be from a neutrino. The event, detected on 11 June 2014, was in the form of a through-going muon, which means that the track originated and ended outside of the detector's volume. So, IceCube cannot measure the total energy of the neutrino, but rather its specific energy loss (dE/dx). While the team is still working on estimating the neutrino energy, the total energy loss visible in the detector was 2.6±0.3 PeV. (Image credit: Leif Radel/IceCube.)*

● *From "Neutrino Hunting in Antarctica" by Spencer Klein, see antarcticaneutrinos.blogspot.ch/.*

Sciencewatch

Compiled by John Swain, Northeastern University

Predator vs prey: how pupil shapes help

While human pupils are round, many animals have elongated pupils, with vertical elongation typical for ambush predators and horizontal elongation for animals that are likely to be prey. Now, Martin Banks of the University of California, Berkeley, and colleagues have an explanation. The key is astigmatism, which predators take advantage of to help catch prey, while prey use it to avoid being caught.

Predators' pupils give them a better ability to judge distance without moving their heads, which might give them away to prey. The pupils of prey give up some vertical focus in exchange for a more panoramic view, while reducing the amount of light from above and below. One simple observation that supports the theory, which anyone can make at a zoo or a farm, is that grazing animals have eyes that rotate 50° or more as they lower their heads to graze, keeping the pupils parallel to the ground. (Human eyes can rotate only a few degrees.) However, more work remains to be done, including explaining why cuttlefish have W-shaped pupils.

Pupils in predator, left, and prey. (Image credits: S Pritchard, left, and Bonmoovol Dreamstime.com.)

● **Further reading**

M S Banks *et al.* 2015 *Sci. Adv.* **1** e1500391.

Opioids from yeast

While predicted to come soon, this result has come sooner than expected: complete biosynthesis of opioids in yeast. Christina Smolke of Stanford University and colleagues engineered yeast to produce the opioids thebaine and hydrocodone, starting from sugar. The work combined enzyme discovery and engineering with pathway and strain optimization. Twenty-one enzyme activities from plants, mammals, bacteria and the yeast itself were needed for thebaine and 23 for hydrocodone. While not yet suited for large-scale production, this proof-of-principle shows that it may eventually be as easy to make opioids as it is to brew beer.

● **Further reading**

S Galanie *et al.* 2015 *Science* DOI: 10.1126/science.aac9373.

Surprising superconductor

While the Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity sets no theoretical bound on how high T_c can be, the highest up to now has been 133 K at ambient pressure and 164 K at high pressure in copper oxide. The new surprise is in sulphur hydride, where a T_c of 80 K had been predicted. Alexander Drozdov of the Max Planck Institute for Chemistry in Mainz and colleagues have found that this material becomes metallic at a pressure of 90 GPa with a T_c of an amazing 203 K. Isotope-shift effects are consistent with BCS theory, and the discovery raises hopes of finding a room-temperature superconductor.

● **Further reading**

A P Drozdov *et al.* 2015 *Nature* DOI:10.1038/nature14964.

High-temperature dielectrics

Dielectric capacitors – the simple ones described in a first course on electromagnetism – would find more uses if they could tolerate temperatures above 150 °C and achieve a larger stored energy density. Polymers have long been a popular choice for dielectrics because of their low cost and ease of manufacture, but the "Moss rule" links increases in polarizability to a lower breakdown voltage for homogeneous polymers. This makes high energy densities seem unlikely, moreover polymers tend to melt or break down at high temperatures.

Qi Li and colleagues at Pennsylvania State University have found that composite polymers can bend or break the Moss rule and tolerate much higher temperatures than had been previously possible. They blend boron-nitride nanosheets (BNNS) with divinyltetramethyldisiloxane-bis(benzocyclobutene) (BCB) and then react the BCB molecules to produce nanocomposites of BNNS in polymeric cross-linked BCB. The result is a dielectric with record properties including a Weibull breakdown strength of 403 MV/m and an energy density of 1.8 J/cm³ at 250 °C. Added bonuses include their being orders of magnitude less conductive than other polymers and their ability to tolerate bending.

● **Further reading**

Q Li *et al.* 2015 *Nature* **523** 576.

Venomous frogs

Brazil's yellow-skinned tree frog, Corythomantis greeningi, *has venom twice as toxic as a pit viper. (Image credit: Jared* et al. *2015.)*

Many frogs are known to be poisonous, which is to say that they have noxious or toxic substances in their skin that afford them passive protection against predators, but they had not been known to inject venom in the way that many snakes and some reptiles do. Now, Edmund Brodie at Utah State University and colleagues have found the first frogs that can actively deliver poison.

The creatures are two species of Brazilian tree frog that have spiny heads with which they can jab a target – using the venomous-frog version of a "head butt" – effectively injecting venom that for one is twice, and the other 25 times, as lethal as that of deadly *Bothrops* pit vipers (also from Brazil). With these first examples of venomous amphibians, the question now is how many more are there?

● **Further reading**

C Jared *et al.* 2015 *Current Biology* **25** 2166.

Astrowatch

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

The universe is getting out of breath

A new study of more than 200,000 galaxies, from the ultraviolet to the far infrared, has provided the most comprehensive assessment of the energy output of the nearby universe. It confirms that the radiation produced by stars in galaxies today is only about half what it was two thousand million years ago. This overall "fading" reflects a decrease in the rate of star formation via the collapse of cool clouds of gas. It seems that the universe is running out of gas – in effect, getting out of breath – and slowly dying.

It is well known to astronomers that the rate of star formation in the universe reached a peak around a redshift $z=2$, when the universe was about 3 Gyr old. Over the subsequent 10 Gyr until now, the production of stars in galaxies has steadily decreased in a given co-moving volume of space – that is, a volume expanding at the same rate as the cosmic expansion of the universe, therefore keeping a constant matter content during the history of the universe. Because the most massive stars are also the most luminous ones and have the shortest lifetimes, the energy output of a galaxy is closely related to its star-formation rate. Indeed, some 100 million years after the formation of a star cluster, its brightest stars would have exploded as supernovas leaving only the lower-mass stars, which are much less luminous.

Although the fading trend of the universe has been known since the late 1990s, measuring it accurately has been a challenge. Part of the difficulty is to gather a representative sample of galaxies at different redshifts and to account properly for all biases. Another complication comes from the obscuration by dust in the galaxies, which absorbs ultraviolet and visible radiation and then re-emits this energy in the infrared. A way to overcome these difficulties is to observe the same region of the sky at many different wavelengths to cover fully the energy output. This has now been achieved by a large international collaboration led by Simon Driver from the International Centre for Radio Astronomy Research (ICRAR), University of Western Australia.

Composite image of one of the more than 200,000 galaxies of the GAMA survey, assembled from observations made at different wavelengths, from the ultraviolet to the infrared. (Image credit: ICRAR/GAMA and ESO.)

The study is part of the Galaxy and Mass Assembly (GAMA) project, the largest multi-wavelength survey ever put together. It used seven of the world's most powerful telescopes to observe more than 200,000 galaxies, each measured at 21 wavelengths from the ultraviolet at 0.1 μm to the far infrared at 500 μm. Driver and collaborators then used this unique data set to derive the spectral energy distribution of the individual galaxies, and the combined one for three different ranges of redshift up to $z=0.20$. For the nearest galaxies, they obtain an average energy output of $(1.5\pm0.3)\times10^{35}$ W produced on average by galaxies in a co-moving volume of a cubic megaparsec, which is equivalent to a cube with a side of about 3.3 million light-years. While this is for a redshift range between $z=0.02$ and $z=0.08$, corresponding to a mean look-back time of 0.75 Gyr, the team finds a significantly higher value of $(2.5\pm0.3)\times10$ W^{35} for a look-back time of 2.25 Gyr ($0.14<z<0.20$). This indicates a decrease by about 10^{35} W in 1.5 Gyr. This trend occurs across all wavelengths and corresponds roughly to a decrease by a factor two over the past two thousand million years.

The ongoing decay of energy production by stars in galaxies also follows the trend of active galactic nuclei and gamma-ray bursts, which were all more numerous and powerful several gigayears ago. The shining, glorious days of the universe are now long past; instead, it will continue to decline, sliding gently into old age, an age of quiescence.

● Further reading

S P Driver *et al.* 2015 *MNRAS* submitted, arXiv:1508.02076.

Picture of the month

This new, colourful image by the Hubble Space Telescope shows the remarkable complexity and beauty of the Twin Jet Nebula. Like other planetary nebulas, the glowing and expanding shells of gas represent the final stages of life for an old star of low-to-intermediate mass (*CERN Courier* Picture of the month July/August 2003 p13; April 2007 p10; March 2012 p12). The particular bipolar outflow clearly visible in this image is thought to result from the presence of a white-dwarf star orbiting the dying star every 100 years. By measuring the expansion of the nebula's wings, astronomers have estimated its age to be only 1200 years. (Image credit: ESA/Hubble & NASA; acknowledgement: Judy Schmidt.)

CERN Courier Archive: 1972

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

Computing

CERN Computing and Data Processing School

After the success of the Varenna School in 1970, a second CERN Computing and Data Processing School was organized from 10–23 September at Pertisau on the shore of the Achensee, an alpine lake in the Austrian Tyrol.

The school brought together a cosmopolitan group of young people working in scientific data processing, to exchange opinions and discuss problems stimulated by experienced lecturers from Western Europe and CERN. The 67 students came from CERN member states, the German Democratic Republic, Israel, Poland, the USSR and Yugoslavia. Lecture topics were divided between pure computer science, applications of small computers in physics, and applied mathematical techniques.


Participants at the 1972 CERN Computing and Data Processing School.

A significant fact to emerge was that the data-handling and control requirements of high-energy physics are becoming so demanding as to require computer applications of greatly increased complexity. Nowadays, experiments use sophisticated equipment and it is essential to monitor the performance of the apparatus. Small computers are widely used for this and standardization is playing an essential role to allow physicists to talk to the equipment in a very simple way, mainly using CAMAC and CAMAC-oriented software.

Another important topic is data communication between scientists working in different laboratories using different hardware and software. A European network of fast data links is technically feasible, but difficulties arise in exchanging information among machines that use different operating systems and speak different dialects. The importance of establishing standards for information exchange was emphasized during one of the informal discussions organized by the students themselves.

● Compiled from texts on pp326–327.

CERN

Public Information Office

From its early days, CERN has had a "public information office", the PIO, the communication channel to the outside world and for many internal-communication tasks. PIO staff are well known to top-class journalists from almost all the member states. Also, many television teams and radio interviewers invade CERN each year, and the PIO either covers their needs or guides them to appropriate CERN contacts. On the film front, the first CERN documentary, *Matter in Question*, appeared in 1961, and is still in limited use although now largely outdated. In recent years, several collaborative films have been made with national television networks, the latest being with the BBC (*CERN Courier* September 2015 p11).

The PIO produces a range of publications, from the pop to the not-so-pop. The mandatory Annual Report, in English and French, is the account of CERN's activities in the previous year. Regular publications are the *Weekly Bulletin* and the monthly *CERN Courier*. Documentation for visitors ranges from the light-hearted "A look at CERN" through to the more formal "CERN and its Laboratories".

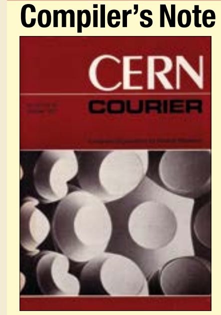
The photo section takes about 8000 photos per year and also some cine film, for example the assembly of the large European bubble chamber BEBC. Important stages of other large projects have been recorded on 16 mm film for archival records.


Reception desk at the Public Information Office, the PIO. (Image credit: CERN-GE-7209076.)

Another major activity is the visits service. Visits are held mostly in French, German or English. About 50 CERN staff, covering many nationalities, act as guides and lecturers. The current annual visitor figure is about 11,000 (excluding Open Days). Two-thirds come on Saturdays, mainly school parties and common-interest groups (farmers, nurses, firms' outings). Midweek visitors are mostly university groups, industrialists from firms working for CERN, and occasional scientists in transit. VIPs obviously receive special attention.

● Compiled from texts on pp327–329.

Compiler's Note



Very few visible characteristics are needed to identity individuals, so some readers may recognize themselves, or erstwhile friends and colleagues, at the computing school in Austria, either in Austria or (wo)manning the PIO.

The overarching concern of the 1972 computing schools was the unrelenting proliferation of data. The physics community was pioneering hardware and software standards for data collection, and had a prescient awareness of the burgeoning need for information sharing and its attendant difficulties. Links and networks were rapidly becoming hot topics across a wide range of applications. Various protocols found favour in different areas until TCP/IP, aka the internet, had gained sufficient diffusion that Tim Berners-Lee could define the hypertext transfer protocol standard to sit on top of it, and the World Wide Web went into orbit around 1990.

And thanks to the Web, nowadays *CERN Courier* is read online by around 30,000 people every month, in addition to a monthly paper print run of about 20,000 copies.

The most precise picture of the proton

The HERA collaborations, H1 and ZEUS, have recently released their definitive paper on measurements of deep-inelastic scattering.

After 15 years of measurement and another eight years of scrutinizing and calculations, the H1 and ZEUS collaborations have published the most precise results to date about the innermost structure and behaviour of the proton. The two collaborations, which took data at DESY's electron–proton collider, HERA, from 1992 to 2007, have combined nearly 3000 measurements of inclusive deep-inelastic cross-sections (H1, ZEUS 2015). With its completion, the paper secures the legacy of the HERA data.

Within the framework of perturbative QCD, the proton is described in terms of parton-density functions, which provide the probability of scattering from a parton, either a gluon or a quark. The H1 and ZEUS collaborations have also produced the first QCD analysis of the data, encompassed in the HERAPDF2.0 sets of parton-distribution functions (PDFs), which form a significant part of the paper. The combined data presented in the new publication will be the basis of all analyses of the structure of the proton for years to come.

As figure 1 depicts, in deep-inelastic scattering, a boson – γ, Z^0 or $W^{\pm}$ – acts as a probe of the structure of the proton by interacting with its constituents, through neutral-current (γ, Z^0) or charged-current ($W^{\pm}$) reactions. Of course, this picture is simplified: the proton is a dynamic structure of quarks and gluons, but by measuring deep-inelastic scattering over a wide kinematic range, this internal structure can be mapped precisely. The variables used to do this are the squared four-momentum, Q^2, of the exchanged boson, and Bjorken x, x_{Bj}, the fraction of the proton's momentum carried by the struck quark.

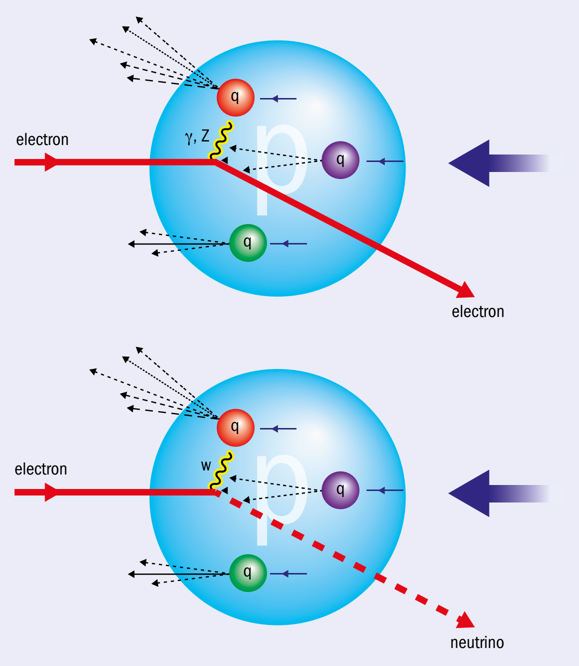


Fig. 1. Diagrams of neutral-current (top) and charged-current (bottom) deep-inelastic electron–proton scattering processes. (Image credit: DESY.)

A wealth of data

The data, taken over the 15-year lifetime of the HERA accelerator, correspond to a total luminosity of about 1 fb^{-1} of deep-inelastic electron–proton and positron–proton scattering. All of the data used were taken with an electron/positron beam energy of 27.5 GeV, with roughly equal amounts of data for electron–proton and positron–proton scattering being recorded. HERA initially operated with a proton-beam energy of 820 GeV, which was increased subsequently to 920 GeV; these data constitute the bulk of the combined measurements. Towards the end of HERA's run, special data samples with a proton-beam energy of 575 GeV and 460 GeV were taken and are also included. The data were combined separately for the e^+p and e^-p runs and for the different centre-of-mass energies. Overall, 41 separate data sets were used in the combination, spanning $0.045 < Q^2 < 50{,}000\ \text{GeV}^2$ and $6 \times 10^{-7} < x_{Bj} < 0.65$, i.e. six orders of magnitude in each variable. The initial measurements consisted of 2937 published cross-sections in total, which were combined to produce 1307 final combined cross-section measurements. These results supersede the previous paper with combined measurements of deep-inelastic scattering cross-sections in which only data up to the year 2000 were combined (*CERN Courier* January/February 2008 p30).

The procedure for combining the data involved a careful treatment of the various uncertainties between all of the data sets. In ▷

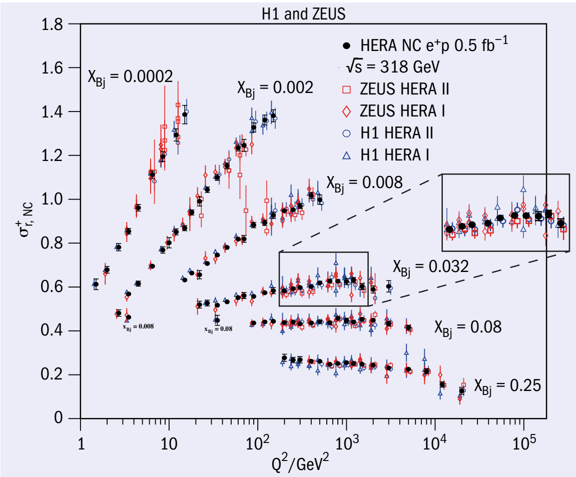


Fig. 2. The newly combined HERA data, together with original data points from H1 and ZEUS from the two running periods, HERA I and HERA II, showing the cross-section for inclusive deep-inelastic scattering versus the photon virtuality, Q^2, at selected values of the parton-momentum fraction, x_{Bj}. These results are for e^+p collisions; a similar sample exists for e^-p collisions. The close-up of a few points clearly reveals the power of the combination procedure.

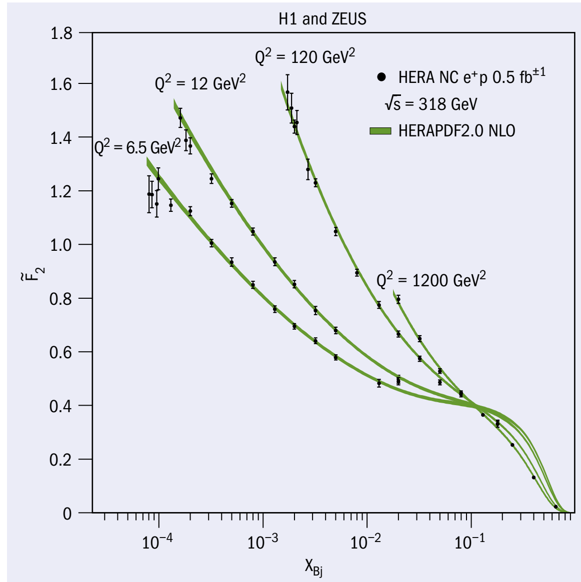


Fig. 3. The proton-structure function extracted from measured cross-sections, shown at four selected values of Q^2. Predictions, with their associated uncertainties, using HERAPDF2.0 at next-to-leading order (NLO) in QCD, are also shown.

particular, the correlations of the various sources were assessed, and those uncertainties deemed to be point-to-point correlated were accounted for as such in the averaging of the data based on a χ^2 minimization method. The resulting χ^2 is 1687 for 1620 degrees of freedom, demonstrating excellent compatibility of the multitude of data sets. Figure 2 illustrates the power of the data combination. It displays a selection of the data in bins of the photon virtuality, Q^2, and for fixed values of x_{Bj}, showing separately individual data sets from several different analyses. A combined data point can be the combination of up to eight individual measurements. The improvement in precision is striking, as is seen more clearly in the close-up on some of the points. An indication of the precision of the combined data is that the total uncertainties are close to 1% for the bulk region of $3 < Q^2 < 500\,\mathrm{GeV}^2$.

As well as showing the precision of the data and power of the combination, the cross-section dependence for the different values of x_{Bj} demonstrates the dynamic structure of the proton in a striking way. For $x_{Bj} = 0.08$, the cross-section dependence is reasonably flat as a function of Q^2. This is known as Bjorken scaling, and is expected from the simple parton model in which inelastic electron–proton scattering is viewed as a sum of elastic electron–parton scattering, where the partons are free point-like objects. At lower values of x_{Bj}, the cross-section rises increasingly more steeply with increasing Q^2 and decreasing x_{Bj}. This effect is known as scaling violation, and is indicative of the density of gluons in the proton increasing.

Such precise knowledge of the PDFs is of highest importance for physics at the LHC.

The increased density and rise of the cross-section can also be observed by considering the proton-structure function F_2 (which is closely related to the cross-section) plotted versus x_{Bj} at fixed Q^2, as in figure 3. The strong rise of F_2 with decreasing x_{Bj} was one of the most important discoveries at HERA. Previous experiments, which were with fixed targets, could not constrain this behaviour, because the data were at low values of Q^2 and high values of x_{Bj}. The figure also shows how the rise towards low x_{Bj} is steeper with increasing Q^2. At higher Q^2, the exchanged boson effectively probes smaller distances, and so can see more of the inner structure of the proton and hence resolves more and more gluons.

Parton distributions

The proton structure of quarks and gluons is often parameterized in terms of the PDFs, which correspond to the probability of finding a gluon or a quark of a given flavour with momentum fraction x in the proton, given the scale μ of the hard interaction. The behaviour of the PDFs with scale is predicted by QCD, but the absolute values need to be determined from fits to data. Using the HERA data, the PDFs can be extracted, while at the same time the evolution as a function of the scale is tested. This analysis is performed at leading order, next-to-leading order (NLO) and next-to-next-to-leading order, yielding the HERAPDF2.0 family of PDFs.

Figure 3 compares the predictions of the PDF analysis at NLO with the measurements of the structure functions. In general, the QCD predictions describe the data well, although this becomes poorer at low Q^2, indicating inadequacies in the theory used at these low scales. Such precise knowledge of the PDFs is also of highest importance for physics at the LHC at CERN, because the uncertainties stemming from the knowledge of the PDFs are increased for proton–proton collisions compared with deep-inelastic scattering.

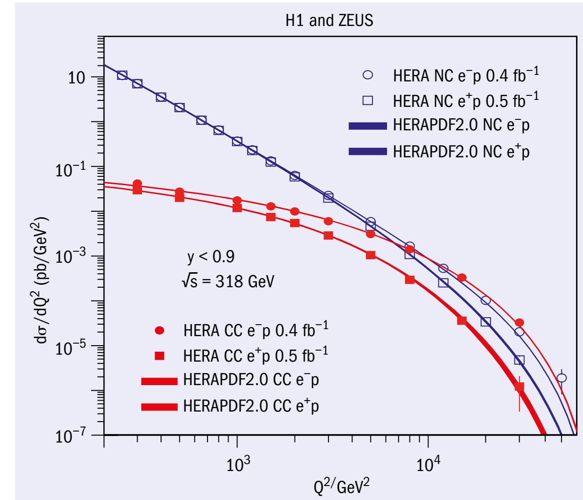


Fig. 4. The HERA combined differential cross-section versus scale, Q^2, for neutral current (NC) and charged current (CC) processes for e^+p and e^-p collisions. Predictions, with their associated uncertainties, using HERAPDF2.0 at NLO in QCD are also shown. Unification of the electromagnetic and weak forces can be seen at high values of Q^2 where the NC and CC cross-sections become similar in magnitude.

The QCD analysis can also be extended to include data from the production of charm quarks and jets at HERA. Charm production is measured again as a function of x_{Bj} and Q^2, however with the condition of detecting a charm meson in the final state. Jet production is measured in the Breit frame, where jets with non-zero transverse momentum are expected from hard QCD processes only. By including the charm and jet data, the analysis becomes particularly sensitive to the strong-coupling constant, $\alpha_s(M_Z)$, whereas without jet data the coupling constant is strongly correlated with the normalization of the gluon density. The combined analysis of inclusive data, charm data and jet data at NLO results in an experimentally very precise measurement of the strong-coupling constant, $\alpha_s(M_Z) = 0.1183 \pm 0.0009$ (exp.), with significantly larger uncertainties of $^{+0.0039}_{-0.0033}$ related to the model and theory.

It is also interesting to look at data from HERA on neutral-current (NC) and charged-current (CC) scattering that is differential in Q^2 but integrated over x_{Bj}, as shown in figure 4 both for e^+p and e^-p. At small Q^2, the cross-sections for NC are much larger than for CC, whereas at large Q^2, in the order of the vector-boson mass squared, they become similar in size. This is a direct visualization of the electroweak unification: the CC process is mediated by weak forces, whereas photon exchange dominates the NC cross-section. Looking in more detail, the NC cross-sections for e^+p and e^-p are almost identical at small Q^2 but start to diverge as Q^2 grows. This is owing to γ–Z^0 interference, which has the opposite effect on the e^+p and e^-p cross-sections. The CC cross-sections also differ between e^+p and e^-p scattering, with two effects contributing: the helicity structure of the $W^\pm$ exchange and the fact that CC e^-p scattering probes the u-valence quarks, whereas d-valence quarks are accessed in CC e^+p.

In summary, the HERA collider experiments H1 and ZEUS have combined their precision data on deep-inelastic scattering, reaching a precision of almost 1% in the double-differential cross-section measurements. It is the largest coherent data set on proton structure, spanning six orders of magnitude in the kinematic variables x_{Bj} and Q^2. A QCD analysis of the HERA data alone results in a set of parton-density functions, HERAPDF2.0, without the need for data from other experiments. Also, using HERA jet and charm data, the strong-coupling constant is measured together with proton PDFs. QCD and electroweak effects are probed at high precision in the same data set, providing beautiful demonstrations of the validity of the Standard Model.

● Further reading

H1, ZEUS 2015 arXiv:1506.06042 [hep-ex].

Résumé

L'image la plus précise du proton

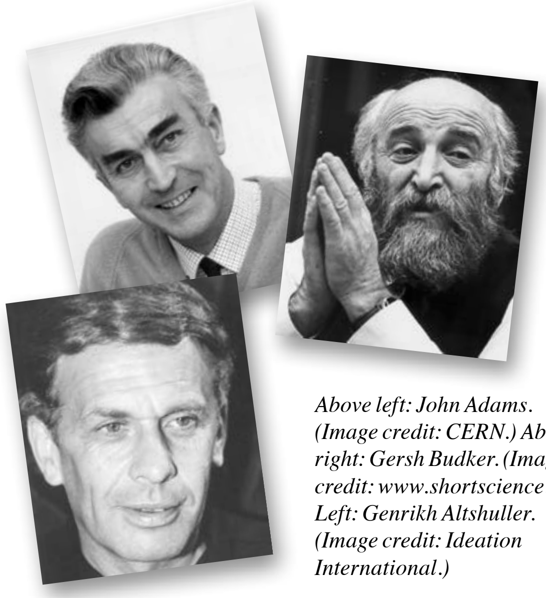
Après 15 années de mesures et huit années supplémentaires d'analyses et de calculs, les collaborations H1 and ZEUS ont publié les résultats les plus précis à ce jour de la structure profonde et du comportement du proton. Les deux collaborations, qui ont enregistré, de 1992 à 2007, des données auprès du collisionneur électron-proton HERA, à DESY, ont combiné près de 3 000 mesures de sections efficaces inclusives profondément inélastiques. La QCD et les effets électrofaibles sont également analysés avec une grande précision dans le même ensemble de données, démontrant brillamment la validité du Modèle standard.

Stefan Schmitt, DESY and H1 spokesperson, and **Matthew Wing**, University College London and ZEUS spokesperson.

Inventing our future accelerator

Could a methodology used for invention in engineering find a role in guiding the innovative process that will be essential for future large-scale accelerator projects?

Can you imagine that electrons
Are planets circling their suns?
Space exploration, wars, elections
And hundreds of computer tongues
Translation by A Seryi of a 1920 poem by Valery Bryusov, "The World of Electron"



Above left: John Adams. (Image credit: CERN.) Above right: Gersh Budker. (Image credit: www.shortscience.ru.) Left: Genrikh Altshuller. (Image credit: Ideation International.)

Accelerator science and technology exhibits a rich history of inventions that now spans almost a century. The fascinating story of accelerator development, which is particularly well described in *Engines of Discovery: A Century of Particle Accelerators* by Andy Sessler and Ted Wilson (*CERN Courier* September 2007 p63), can also be summarized in the so-called "Livingston plot", where the equivalent energy of an accelerated beam is shown as a function of time. The plot depicts how new accelerating technologies take over once the previous technology has reached its full potential, so that over the course of many decades the maximum achieved energy has continued to grow exponentially, thanks to many inventions and the development of many different accelerator technologies. The most recent decades have also been rich with inventions, such as the photon-collider concept (still an idea), crab-waist collisions (already verified experimentally at the DAFNE storage ring in Frascati) and integrable optics for storage rings (verification is planned at the Integrable Optics Test Accelerator at Fermilab), to name a few.

Despite recent inventions, however, there is some cause for anxiety about the latest progress in the field and projections for the future. The three most recent decades represented by the Tevatron and the LHC exhibit a much slower energy growth over time. This may be an indication that the existing technologies for acceleration have come to their maximum potential, and that further progress will demand the creation of a new accelerating method – one that is more compact and economical. There are indeed several emerging acceleration techniques, such as laser-driven and beam-driven plasma acceleration (*CERN Courier* June 2007 p28), which can perhaps bring the Livingston plot back to the fast-rising exponent.

Nevertheless, inspired by the variety of past inventions in the field, and dreaming about future accelerators that will require many scientific and technological breakthroughs, we can pose the question: how can we invent more efficiently?

It is worth recalling two biographical facts about two prominent accelerator scientists: John Adams, who in the 1950s played the key role in implementing the courageous decision to cancel the already approved 10 GeV weak-focusing accelerator for a totally innovative 25 GeV strong-focusing machine (the CERN Proton Synchrotron), and Gersh Budker, who was the founder and first director of the Institute of Nuclear Physics, Novosibirsk, and inventor of many innovations in the field of accelerator physics, such as electron cooling. It is important in this context that Adams had a unique combination of scientific and engineering abilities, and that Budker was once called by Lev Landau a "relativistic engineer". This connection is indeed notable, because the art of inventiveness that I am about to discuss came from engineering.

While everyone has probably heard about problem-solving approaches such as brainstorming or even its improved version, synectics (the use of a fairy-tale-style description of the problem is one of its approaches – note the snakes in figure 1c (p27) ▷

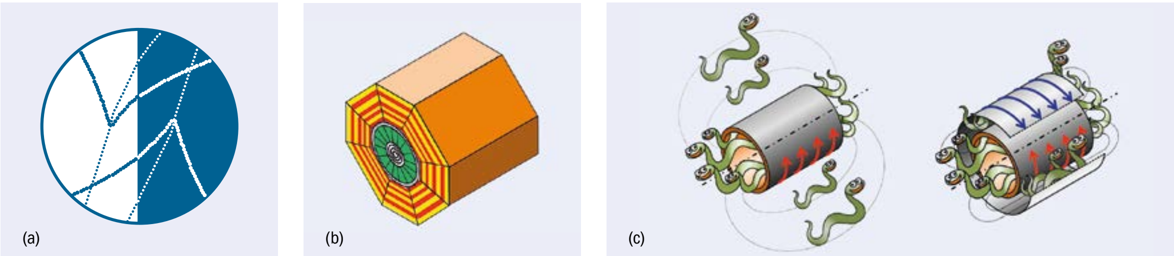


Fig. 1. Examples of inventive principles of TRIZ in particle physics. Left to right: (a) The system/anti-system of cloud and bubble chambers. (b) The nested-doll principle of a collider detector. (c) Both of these principles at work in a force-neutral solenoid; the system with nested solenoids of opposite currents, right, limits the region of flux-return – keeping the snakes under control in an example of the power of metaphor to aid creative thinking. (Image credits: Elena Seraia.)

representing the magnetic fields in the solenoid), it is likely that most people working in science have never heard about the inventive methodologies that engineers have developed and used. It is indeed astonishing that formal inventive approaches, so widely used in industry, are rarely known in science.

One such approach is TRIZ – pronounced "treez" – which can be translated as the Theory of Inventive Problem Solving. TRIZ was developed by Genrikh Altshuller in the Soviet Union in the mid-20th century. Starting in 1946 when he was working in a patent office, but interrupted by a dramatic decade-long turmoil in his life (another story) that he overcame to resume his studies, Altshuller analysed many thousands of patents, trying to discover patterns to identify what makes a patent successful. Following his work in the patent office, between 1956 and 1985 he formulated TRIZ and, together with his team, developed it further. Since then, TRIZ has gradually become one of the most powerful tools in the industrial world. For example, in his 7 March 2013 contribution to the business magazine *Forbes*, "What Makes Samsung Such An Innovative Company?", Haydn Shaughnessy wrote that TRIZ "became the bedrock of innovation at Samsung", and that "TRIZ is now an obligatory skill set if you want to advance within Samsung".

A methodology

The authors of TRIZ devised the following four cornerstones for the method: the same problems and solutions appear again and again but in different industries; there is a recognizable technological evolution path for all industries; innovative patents (which are about a quarter of the total) use science and engineering theories outside of their own area or industry; and an innovative patent uncovers and solves contradictions. In addition, the team created a detailed methodology, which employs tables of typical contradicting parameters and a wonderfully universal table of 40 inventive principles. The TRIZ method consists in finding a pair of contradicting parameters in a problem, which, using the TRIZ inventive tables, immediately leads to the selection of only a few suitable inventive principles that narrow down the choice and result in a faster solution to a problem.

TRIZ textbooks often cite Charles Wilson's cloud chamber (invented in 1911) and Donald Glaser's bubble chamber (invented in 1952) as examples – to use the terminology of TRIZ – of a system and anti-system. Indeed, the cloud chamber works on the principle of bubbles of liquid created in gas, whereas the bubble chamber uses bubbles of gas created in liquid (figure 1a). If the TRIZ inventive principle of system/anti-system were applied, the invention of the bubble chamber would follow immediately and not almost half a century after the invention of the cloud chamber.

Another TRIZ inventive principle, that of Russian dolls (nested dolls, or matryoshki), can be applied not only to engineering but also in many other areas, including science or even philology. The principle of a concept inside a concept can be seen in the British nursery rhyme "This is the house that Jack built", and the 1920 poem by Valery Bryusov (quoted at the start), which describes an electron as a planet in its own world, can also be seen as a reflection of the nested-doll inventive principle, this time in poetic science fiction. A spectacular scientific example is the construction of a high-energy physics detector, where many different sub-detectors are inserted into one another, to enhance the accuracy of detecting elusive particles (figure 1b). Such detectors are needed to find out if there is indeed a world inside of an electron – and the circle is now closed!

The TRIZ method can be applied, in particular, to accelerator science. For example, the dual force-neutral solenoid found in the interaction region of a collider, or in NMR scanners, is an illustration of both the nested-doll and the system/anti-system inventive principles. Two solenoids of opposite currents are inserted in one another in such a way that all of the magnetic flux-return is between the solenoids and none is seen outside, reducing the need for magnetic shielding in case of NMR or reducing interference with the main solenoid of the detector in case of a particle collider (figure 1c). Remarkably, the same combination of inventive principles can be seen in the technique of stimulated emission depletion microscopy (STED), which was rewarded with the 2014 Nobel Prize in Chemistry. The final focus system at a collider with non-local chromaticity correction is an illustration of the inventive principle of what is known as "beforehand cushioning". And so on.

It is astonishing that formal inventive approaches are rarely known in science.

While many of the TRIZ inventive principles can be applied directly to problems in accelerator science, it is tempting to add accelerator-science-related parameters and inventive principles to TRIZ.

The equations of Maxwell or of thermodynamics, where an integral on a surface is connected to the integral over volume, suggest an inventive principle of changing the volume-to-surface ratio of an object. Nature provides an illustration in a smart cat, stretched out under the sun or curled up in the cold, but flat colliding electron–positron beams or fibre lasers also illustrate the same principle. Another possible inventive principle for accelerator science is the use of non-damageable or already damaged materials: the laser wire for beam diagnostics, the mercury jet as a beam target, plasma acceleration, or a plasma mirror – the list of examples illustrating this inventive principle can be continued.

So the TRIZ method of inventiveness, although created originally for engineering, is universal and can also be applied to science. TRIZ methodology provides another way to look at the world; combined with science it creates a powerful and eye-opening amalgam of science and inventiveness. It is particularly helpful for building bridges of understanding between completely different scientific disciplines, and so is also naturally useful to educational and research organizations that endeavour to break barriers between disciplines.

However, experience shows that knowledge of TRIZ is nearly non-existent in the scientific departments of western universities. Moreover, it is not unusual to hear about unsuccessful attempts to introduce TRIZ into the graduate courses of universities' science departments. Indeed, in many or most of these cases, the apparent reason for the failure is that the canonical version of TRIZ was introduced to science PhD students in the same way that TRIZ is taught to engineers in industrial companies. This may be a mistake, because science students are rightfully more critically minded and justifiably sceptical about overly prescriptive step-by-step methods. Indeed, a critically thinking scientist would immediately question the canonical number of 40 inventive principles, and note that identifying just a pair of contradicting parameters is a first-order approximation, and so on.

A more suitable approach to introduce TRIZ to graduate students, which takes into account the lessons learnt by its predecessors, could be different. Instead of teaching graduate students the ready-to-use methodology, it might be better to take them through the process of recreating parts of TRIZ by analysing various inventions and discoveries from scientific disciplines, showing that the TRIZ inventive principles can be efficiently applied to science. In the process, additional inventive principles that are more suitable for scientific disciplines could be found and added to standard TRIZ. In my recent textbook, I call this extension "Accelerating Science (AS) TRIZ", where "accelerating" refers not to accelerators, but instead highlights that TRIZ can help to boost various areas of science.

Many of the examples of TRIZ-like inventions in science considered above have already been made, and I am being deliberately provocative in connecting them to TRIZ *post factum*. However, it is natural to wonder whether TRIZ and AS-TRIZ could actually help to inspire and create new scientific inventions and innovations, especially in regard to projects that continue to manifest many unsolved obstacles.

One example of such a project is the circular collider currently being considered as a successor to the LHC – the Future Circular Collider (FCC), a 100 km circumference machine (*CERN Courier* April 2014 p16). This project has many scientific and technical tasks and challenges that need to be solved. Notably, the total energy in each circulating proton beam is expected to exceed 8 GJ, which is equivalent to the kinetic energy of an Airbus-380 flying at 720 km/h. Not only does such a beam need to be handled safely in the bending magnets, it also needs to be focused in the interaction region to a micrometre-size spot – the equivalent, more or less, of having to pass through the eye of a needle.

It remains to be seen if the methodology of TRIZ and AS-TRIZ can be applied to such a large-scale project as the FCC, because it brings a whole array of new, difficult and exciting challenges to the table. Nonetheless, it is certainly a project that can only flourish with the application of knowledge and inventiveness.

● Further reading

G Altshuller 1999 *The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity* (translated by Lev Shulyak and Steven Rodman) Technical Innovation Center, Inc.

Résumé

Inventer notre futur accélérateur

L'énergie maximale atteignable par un accélérateur de particules a augmenté de façon exponentielle au fil des décennies grâce à de nombreuses inventions et au développement de diverses technologies d'accélérateurs. Aujourd'hui, toutefois, certains s'inquiètent du potentiel de progrès restant dans la discipline. Inspiré par la diversité des inventions passées, et rêvant de futurs accélérateurs qui nécessiteront de nombreuses avancées scientifiques et techniques, Andreï Seryi s'interroge : comment pouvons-nous inventer plus efficacement ? Ne pourrait-on pas tirer parti d'une méthodologie d'invention utilisée en ingénierie pour orienter le processus d'innovation qui sera essentiel pour les futurs projets d'accélérateurs à grande échelle ?

Andrei Seryi, director of the John Adams Institute, University of Oxford. He is the author of *Unifying Physics of Accelerators, Lasers and Plasma* (2015, CRC Press), available at 20% discount to readers who order online at www.crcpress.com, quoting code AZP98.

CERN Courier October 2015
Detector R&D

RD51 and the rise of micro-pattern gas detectors

Since its foundation, the RD51 collaboration has provided important stimulus for the development of MPGDs.

Improvements in detector technology often come from capitalizing on industrial progress. Over the past two decades, advances in photolithography, microelectronics and printed circuits have opened the way for the production of micro-structured gas-amplification devices. By 2008, interest in the development and use of the novel micro-pattern gaseous detector (MPGD) technologies led to the establishment at CERN of the RD51 collaboration. Originally created for a five-year term, RD51 was later prolonged for another five years beyond 2013. While many of the MPGD technologies were introduced before RD51 was founded (figure 1), with more techniques becoming available or affordable, new detection concepts are still being introduced, and existing ones are substantially improved.

In the late 1980s, the development of the micro-strip gas chamber (MSGC) created great interest because of its intrinsic rate-capability, which was orders of magnitude higher than in wire chambers, and its position resolution of a few tens of micrometres at particle fluxes exceeding about 1 MHz/mm^2. Developed for projects at high-luminosity colliders, MSGCs promised to fill a gap between the high-performance but expensive solid-state detectors, and cheap but rate-limited traditional wire chambers. However, detailed studies of their long-term behaviour at high rates and in hadron beams revealed two possible weaknesses of the MSGC technology: the formation of deposits on the electrodes, affecting gain and performance ("ageing effects"), and spark-induced damage to electrodes in the presence of highly ionizing particles.

These initial ideas have since led to more robust MPGD structures, in general using modern photolithographic processes on thin insulating supports. In particular, ease of manufacturing, operational stability and superior performances for charged-particle tracking, muon detection and triggering have given rise to two main designs: the gas electron-multiplier (GEM) and the micro-mesh gaseous structure (Micromegas). By using a pitch size of a few hundred micrometres, both devices exhibit intrinsic high-rate capability (> 1 MHz/mm^2), excellent spatial and multi-track resolution (around 30 μm and 500 μm, respectively), and time resolution for single photoelectrons in the sub-nanosecond range.

Coupling the microelectronics industry and advanced PCB technology has been important for the development of gas detectors with increasingly smaller pitch size. An elegant example is the use of a CMOS pixel ASIC, assembled directly below the GEM or Micromegas amplification structure. Modern "wafer post-processing technology" allows for the integration of a Micromegas grid directly on top of a Medipix or Timepix chip, thus forming

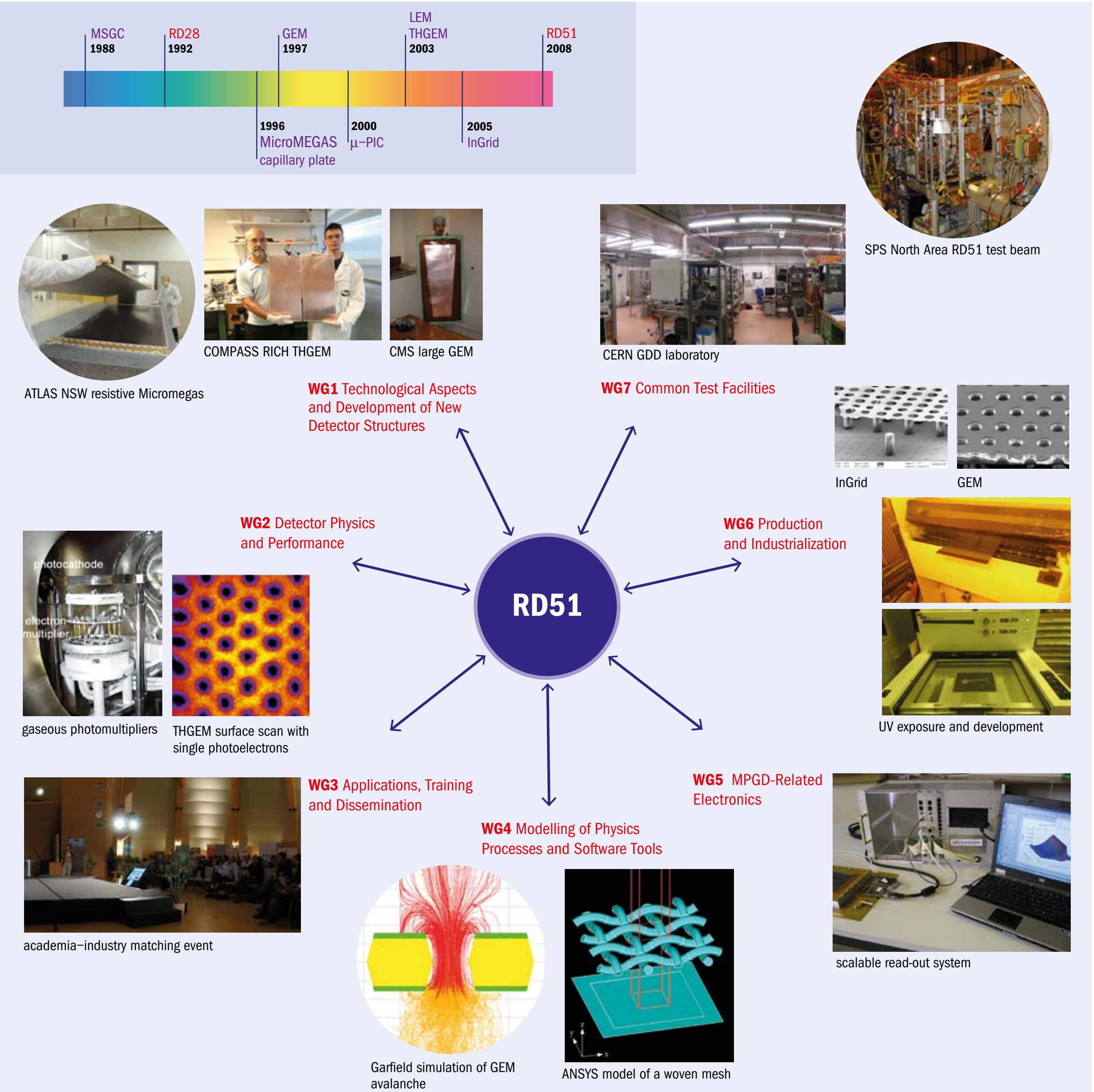


Fig. 1. The seven working groups of RD51, with illustrations of just a few examples of the different kinds of work involved. Top left: the 20-year pre-history of RD51. (Image credits: RD51 Collaboration.)

integrated read-out of a gaseous detector (InGrid). Using this approach, MPGD-based detectors can reach the level of integration, compactness and resolving power typical of solid-state pixel devices. For applications requiring imaging detectors with large-area coverage and moderate spatial resolution (e.g. ring-imaging Cherenkov (RICH) counters), coarser macro-patterned structures offer an interesting economic solution with relatively low mass and easy construction – thanks to the intrinsic robustness of the PCB electrodes. Such detectors are the thick GEM (THGEM), large electron multiplier (LEM), patterned resistive thick GEM (RETGEM) and the resistive-plate WELL (RPWELL).

RD51 and its working groups

The main objective of RD51 is to advance the technological development and application of MPGDs. While a number of activities have emerged related to the LHC upgrade, most importantly, RD51 serves as an access point to MPGD "know-how" for the worldwide community – a platform for sharing information, results and experience – and optimizes the cost of R&D through the sharing of resources and the creation of common projects and infrastructure. All partners are already pursuing either basic- or application-oriented R&D involving MPGD concepts. Figure 1 shows the organization of seven Working Groups (WG) that cover all of the relevant aspects of MPGD-related R&D.

WG1 Technological Aspects and Development of New Detector Structures. The objectives of WG1 are to improve the performance of existing detector structures, optimize fabrication methods, and develop new multiplier geometries and techniques. One of the most prominent activities is the development of large-area GEM, Micromegas and THGEM detectors. Only one decade ago, the largest MPGDs were around 40 × 40 cm^2, limited by existing tools and materials. A big step towards the industrial manufacturing of MPGDs with a size around a square metre came with new fabrication methods – the single-mask GEM, "bulk" Micromegas, and the novel Micromegas construction scheme with a "floating mesh". While in "bulk" Micromegas, the metallic mesh is integrated into the PCB read-out, in the "floating-mesh" scheme it is integrated in the panel containing drift electrodes and placed on pillars when the chamber is closed. The single-mask GEM technique overcomes the cumbersome practice of alignment of two masks between top and bottom films, which limits the achievable lateral size to 50 cm. This technology, together with the novel "self-stretching technique" for assembling GEMs without glue and spacers, simplifies the fabrication process to such an extent that, especially for large-volume production, the cost per unit area drops by orders of magnitude. ▷

Another breakthrough came with the development of Micromegas with resistive electrodes for discharge mitigation. The resistive strips match the pattern of the read-out strips geometrically, but are electrically insulated from them. Large-area resistive electrodes to prevent sparks have been developed using two different techniques: screen printing and carbon sputtering. The technology of the THGEM detectors is well established in small prototypes, the major challenge is the industrial production of high-quality large-size boards. A novel MPGD-based hydrid architecture, consisting of double THGEM and Micromegas, has been developed for photon detection; the latter allows a significant reduction in the ion backflow to the photocathode. A spark-protected version of THGEM (RETGEM), where the copper-clad conductive electrodes are replaced by resistive materials, and the RPWELL detector, consisting of a single-sided THGEM coupled to the read-out electrode through a sheet of large bulk resistivity, have also been manufactured and studied. To reduce discharge probability, a micro-pixel gas chamber (µ-PIC) with resistive electrodes using sputtered carbon has been developed; this technology is easily extendable for the production of large areas up to a few square metres.

To reduce costs, further work is needed for developing radiation-hard read-out and reinventing mainstream technologies under a new paradigm of integration of electronics and detectors, as well as integration of functionality, e.g. integrating read-out electronics directly into the MPGD structure. A breakthrough here is the development of a time-projection chamber (TPC) read-out with a total of 160 InGrid detectors, each $2\,cm^2$, corresponding to 10.5 million pixels. Despite the enormous challenges, this has demonstrated for the first time the feasibility of extending the Timepix CMOS read-out of MPGDs to large areas.

WG2 Detector Physics and Performance. The goal of WG2 is to improve understanding of the basic physics phenomena in gases, to define common test standards, which allow comparison and eventually selection among different technologies for a particular application, and to study the main physics processes that limit MPGD performance, such as sparking, charging-up effects and ageing.

Primary ionization and electron multiplication in avalanches are statistical processes that set limits to the spatial, energy and timing resolution, and so affect the overall performance of a detector. Exploiting the ability of Micromegas and GEM detectors to measure both the position and arrival time of the charge deposited in the drift gap, a novel method – the µTPC – has been developed for the case of inclined tracks, allowing for a precise segment reconstruction using a single detection plane, and significantly improving spatial resolution (well below 100 µm, even at large track angles). Excellent energy resolution is routinely achieved with "microbulk" Micromegas and InGrid devices, differing only slightly from the accuracy obtained with gaseous scintillation proportional counters and limited by the Fano factor. Moreover, "microbulk" detectors have very low levels of intrinsic radioactivity. Other recent studies have revealed that Micromegas could act as a photodetector coupled to a Cherenkov-radiator front window, in a set-up that produces a sufficient number of UV photons to convert single-photoelectron time jitter of a few hundred picoseconds into an incident-particle timing response of the order of 50 ps.

MPGDs are being used in, for example, plasma diagnostics, material sciences, and medical physics.

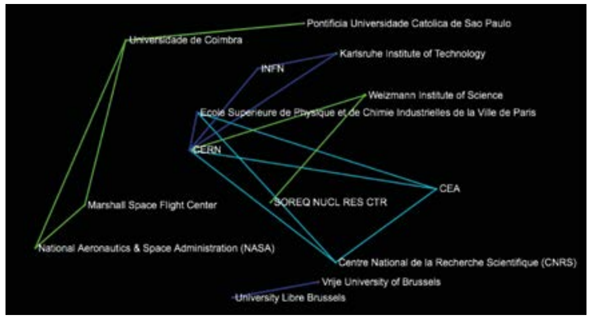
One of the central topics of WG2 is the development of effective protection against discharges in the presence of heavily ionizing particles. The limitation caused by occasional sparking is now being lifted by the use of resistive electrodes, but at the price of current-dependent charging-up effects that cause a reduction in gain. Systematic studies are needed to optimize the electrical and geometrical characteristics of resistive Micromegas in terms of the maximum particle rate. Recent ageing studies performed in view of the High-Luminosity LHC upgrades confirmed that the radiation hardness of MPGDs is comparable with solid-state sensors in harsh radiation environments. Nevertheless, it is important to develop and validate materials with resistance to ageing and radiation damage.

Many of the advances involve the use of new materials and concepts – for example, a GEM made out of crystallized glass, and a "glass piggyback" Micromegas that separates the Micromegas from the actual read-out by a ceramic layer, so that the signal is read by capacitive coupling and the read-out is immune to discharges. A completely new approach is the study of charge-transfer properties through graphene for applications in gaseous detectors.

Working at cryogenic temperatures – or even within the cryogenic liquid itself – requires optimization to achieve simultaneously high gas gain and long-term stability. Two ideas have been pursued for future large-scale noble-liquid detectors: dual-phase TPCs with cryogenic large-area gaseous photomultipliers (GPMs) and single-phase TPCs with MPGDs immersed in the noble liquid. Studies have demonstrated that the copious light yields in liquid xenon, and the resulting good energy resolution, are a result of electroluminescence occurring within xenon-gas bubbles trapped under the hole electrode.

WG3 Applications, Training and Dissemination. WG3 concentrates on the application of MPGDs and on how to optimize detectors for particularly demanding cases. Since the pioneering use of GEM and Micromegas by the COMPASS experiment at CERN – the first large-scale use of MPGDs in particle physics – they have spread to colliders. Their use in mega-projects at accelerators is very important to engage people with science and to receive public recognition. During the past five years, there have been major developments of Micromegas and GEMs for various upgrades for ATLAS, CMS and ALICE at the LHC, as well as THGEMs for the upgrade of the COMPASS RICH. Although normally used as flat detectors, MPGDs can be bent to form cylindrically curved, ultra-light tracking systems as used in inner-tracker and vertex applications. Examples are cylindrical GEMs for the KLOE2 experiment at the DAFNE e^+e^- collider and resistive Micromegas for CLAS12 at Jefferson Lab. MPGD technology can also fulfil the most stringent constraints imposed by future facilities, from the Facility for Antiproton and Ion Research to the International Linear Collider and Future Circular Collider.

MPGDs have also found numerous applications in other fields of fundamental research. They are being used or considered, for example, for X-ray and neutron imaging, neutrino–nucleus scattering



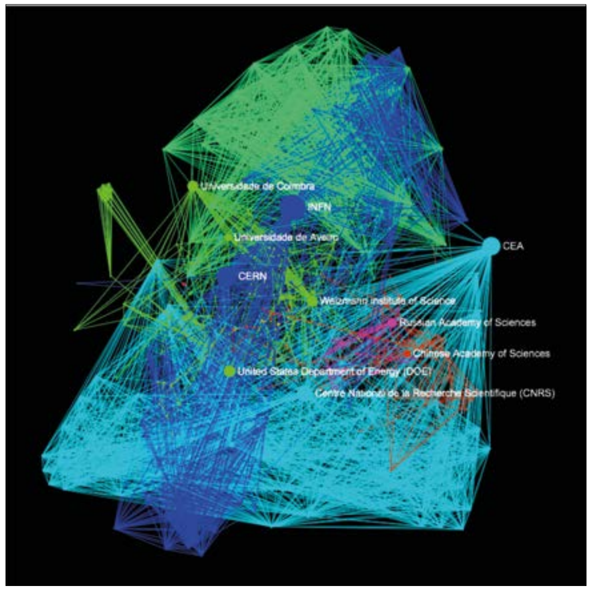


Fig. 2. A combined map of organizations working with MPGDs built with collaboration-spotting software developed at CERN, showing the huge growth in interest between 1998, left, and 2015, right. (Image credit: Collaboration Spotting/collspotting.web.cern.ch.)

experiments, dark-matter and astrophysics experiments, plasma diagnostics, material sciences, radioactive-waste monitoring and security applications, medical physics and hadron therapy.

To help in further disseminating MPGD applications beyond fundamental physics, academia–industry matching events were introduced when the continuation of the RD51 was discussed in 2013. Since then, three events have been organized by RD51 in collaboration with the HEPTech network (*CERN Courier* April 2015 p17), covering MPGD applications in neutron and photon detection. The events provided a platform where academic institutions, potential users and industry could meet to foster collaboration with people interested in MPGD technology. In the case of neutron detection, there is tangible mutual interest between the high-energy physics and neutron-scattering communities to advance the technology of MPGDs; GEM-based solutions for thermal-neutron detection at spallation sources, novel high-resolution neutron devices for macromolecular crystallography, and fast neutron MPGD detectors in fusion research represent a new frontier for future developments.

WG4 Modelling of Physics Processes and Software Tools. Fast and accurate simulation has become increasingly important as the complexity of instrumentation has increased. RD51's activity on software tools and the modelling of physics processes that make MPGDs function provides an entry point for institutes that have a strong theoretical background, but do not yet have the facilities to do experimental work. One example is the development of a nearly exact boundary-element solver, which is in most aspects superior to the finite-element method for gas-detector simulations. Another example is the dedicated measurement campaign and data analysis programme that was undertaken to understand avalanche statistics and determine the Penning transfer-rates in numerous gas mixtures.

The main difference between traditional wire-based devices and MPGDs is that the electrode size of order 10 µm in MPGDs is comparable to the collision mean free path. Microscopic tracking algorithms (Garfield++) developed within WG4 have shed light on the effects of surface and space charge in GEMs, as well as on the transparency of meshes in Micromegas. The microscopic tracking technique has also led to better understanding of the avalanche-size statistics, clarifying in particular why light noble gases perform better than heavier noble gases. Significant effort has also been devoted to modelling the performance of MPGDs for particular applications – for example, studies of electron losses in Micromegas with different mesh specifications, and of GEM electron transparency, charging-up and ion-backflow processes, for the ATLAS and ALICE upgrades.

WG5 MPGD-Related Electronics. Initiated in WG5 in 2009 as a basic multichannel read-out-system for MPGDs, the scalable read-out system (SRS) electronics has evolved into a popular RD51 standard for MPGDs. Many groups contribute to SRS hardware, firmware, software and applications, and the system has already extended beyond RD51. SRS is generally considered to be an "easy-to-use" portable system from detector to data analysis, with read-out software that can be installed on a laptop for small laboratory set-ups. Its scalability principle allows systems of 100,000 channels and more to be built through the simple addition of more electronic SRS slices, and operated at very high bandwidth using the online software of the LHC experiments. The front-end adapter concept of SRS represents another degree of freedom, because basically any sensor technology typically implemented in multi-channel ASICs may be used. So far, five different ASICs have been implemented on SRS hybrids as plug-ins for MPGDs: APV25, VFAT, Beetle, VMM2 and Timepix.

The number of SRS systems deployed is now nearing 100, with more than 300,000 APV channels, corresponding to a total volume of SRS sales of around CHF1 million. SRS has been ported for the read-out of photon detectors and tracking detectors, and is being used in several of the upgrades for ALICE, ATLAS, CMS and TOTEM at the LHC. Meanwhile, CERN's Technology Transfer group has granted SRS reproduction licences to several companies. Since 2013, SRS has been re-designed according to the ATCA industry standard, which allows for much higher ▷

channel density and output bandwidth.

WG6 Production and Industrialization. A key point that must be solved in WG6 to advance cost-effective MPGDs is the manufacturing of large-size detectors and their production by industrial processes. The CERN PCB workshop is a unique MPGD production facility, where generic R&D, detector-component production and quality control take place. Today, GEM and Micromegas detectors can reach areas of 1 m² in a single unit and nearly 2 m² by patching some elements inside the detectors. Thanks to the completion of the upgrade to its infrastructure in 2012, CERN is still leading in the MPGD domain in terms of maximum detector size; however, more than 10 companies are already producing detector parts of reasonable size. WG6 serves as a reference point for companies interested in MPGD manufacturing and helps them to reach the required level of competences. Contacts with some have strengthened to the extent that they have signed licence agreements and engaged in a technology-transfer programme co-ordinated within WG6. As an example, the ATLAS New Small Wheel (NSW) upgrade will be the first detector mass produced in industry using a large high-granularity MPGD, with a detecting area around 1300 m² divided into 2 m × 0.5 m detectors.

WG7 Common Test Facilities. The development of robust and efficient MPGDs entails understanding of their performance and implies a significant investment for laboratory measurements and detector test-beam activities to study prototypes and qualify final designs. Maintenance of the RD51 lab at CERN and test-beam facilities plays a key role among the objectives of WG7. A semi-permanent common test-beam infrastructure has been installed at the H4 test-beam area at CERN's Super Proton Synchrotron for the needs of the RD51 community. It includes three high-precision beam telescopes made of Micromegas and GEM detectors, data acquisition, services, and gas-distribution systems. One advantage of the H4 area is the "Goliath" magnet (around 1.5 T over a large area), allowing tests of MPGDs in a magnetic field. RD51 users can also use the instrumentation, services and infrastructures of the Gas Detector Development (GDD) laboratory at CERN, and clean rooms are accessible for assembly, modification and inspection of detectors. More than 30 groups use the general RD51 infrastructure every year as a part of the WG7 activities; three annual test-beam campaigns attract on average three to seven RD51 groups at a time, working in parallel.

The RD51 collaboration also advances the MPGD domain with scientific, technological and educational initiatives. Thanks to RD51's interdisciplinary and inter-institutional co-operation, the University Antonio Nariño in Bogota has built a detector laboratory where doctoral students and researchers are trained in the science and technology of MPGDs. With this new infrastructure and international support, the university is leveraging co-operation with other Latin American institutes to build a critical mass around MPGDs in this part of the world.

Given the ever-growing interest in MPGDs, RD51 re-established an international conference series on the detectors. The first meeting in the new series took place in Crete in 2009, followed by Kobe in 2011 and Zaragoza in 2013 (*CERN Courier* November 2013 p33). This year, the collaboration is looking forward to holding the fourth MPGD conference in Trieste, on 12–15 October.

The vitality of the MPGD community resides in the relatively large number of young scientists, so educational events constitute an important activity. A series of specialized schools, comprising lectures and hands-on training for students, engineers and physicists from RD51 institutes, has been organized at CERN covering the assembly of MPGDs (2009), software and simulation tools (2011), and electronics (2014). This is particularly important for young people who are seeking meaningful and rewarding work in research and industry. Last year, RD51 co-organized the MPGD lecture series and the IWAD conference in Kolkata, the Danube School on Instrumentation in Novi Sad, and the special "Charpak Event" in Lviv, organized in the context of CERN's 60th anniversary programme "60 Years of Science for Peace" (*CERN Courier* November 2014 p38). The latter was organized at a particularly fragile time for Ukraine, to enhance the role of science diplomacy to tackle global challenges via the development of novel technologies.

In conclusion

During the past 10 years, the deployment of MPGDs in operational experiments has increased enormously, and RD51 now serves a broad user community, driving the MPGD domain and any potential commercial applications that may arise. Because of a growing interest in the benefits of MPGDs in many fields of research, technologies are being optimized for a broad range of applications, demonstrating the capabilities of this class of detector. Today, RD51 is continuing to grow, and now has more than 90 institutes and 450 participants from more than 30 countries in Europe, America, Asia and Africa. Last year, six new institutes from Spain, Croatia, Brazil, Korea, Japan and India joined the collaboration, further enhancing the geographical diversity and expertise of the MPGD community. Since its foundation, RD51 has provided a fundamental boost from isolated developers to a world-wide MPGD network, as illustrated by collaboration-spotting software (figure 2, p29). Many opportunities are still to be exploited, and RD51 will remain committed to the quest to help shape the future of MPGD technologies and pave the way for novel applications.

● For more information about RD51, visit http://rd51-public.web.cern.ch/RD51-Public/.

Résumé

RD51 et l'essor des détecteurs gazeux à micropistes

En 2008 a été créée au CERN la collaboration RD51, répondant ainsi au besoin de développer et d'utiliser les techniques innovantes des détecteurs gazeux à micropistes (MPGD). Si nombre de ces technologies ont été adoptées avant la création de RD51, d'autres techniques sont apparues depuis ou sont devenues accessibles, de nouveaux concepts de détection sont en cours d'adoption et des techniques actuelles font l'objet d'améliorations importantes. Parallèlement, le déploiement de détecteurs MPGD dans des expériences en exploitation s'est considérablement accru. Aujourd'hui, RD51 est au service d'une vaste communauté d'utilisateurs, veillant sur le domaine des détecteurs MPGD et sur les applications commerciales qui pourraient voir le jour.

Leszek Ropelewski, CERN, and **Maxim Titov**, CEA Saclay.

EPS-HEP 2015

Vienna hosts a high-energy particle waltz

The first major summer conference in particle physics, EPS-HEP 2015 in Vienna offered participants the opportunity to hear all of the latest news in the field first hand.

Participants relax in the arcade courtyard during the welcome reception at the University of Vienna. (All image credits: Konrad, Lettenbichler, Weinwurm/ÖAW.)

The first results at a new high-energy frontier in particle physics were a major highlight for the 2015 edition of the European Physical Society Conference on High Energy Physics (EPS-HEP). The biennial conference took place at the University of Vienna on 22–29 July, only weeks after data taking at the LHC at CERN had started at the record centre-of-mass energy of 13 TeV. In addition to the hot news from the LHC, the 723 participants from all over the world were also able to share a variety of exciting news in different areas of particle and astroparticle physics, presented in 425 parallel talks, 194 posters and 41 plenary talks. The following report focuses on a few selected highlights, including the education and outreach session – a "first" for EPS-HEP conferences (see box p34).

After more than two years of intense work during the first long shutdown, the LHC and the experiments have begun running again, ready to venture into unexplored territories and perhaps observe physics beyond the Standard Model, following the discovery of the Higgs boson in 2012. Both the accelerator teams and the LHC experimental collaborations made a huge effort to provide collisions and to gather physics data in time for EPS-HEP 2015. By mid-July, the experiments had already recorded 100 times more data than they had at around the same time after the LHC had started up at 7 TeV in 2010, and the collaborations had worked hard to be able to bring the first results using 2015 data.

Talks at the conference provided detailed information about the operation of the accelerator and expectations for the near and distant future. The ATLAS, CMS and LHCb collaborations all presented results at 13 TeV for the first time (*CERN Courier* September 2015 pp8–11). Measurements of the charged-particle production rate as a function of rapidity provide a first possibility to test hadronic physics models in the new energy region. Several known resonances, such as the J/ψ and the Z and W bosons, have been rediscovered at these higher energies, and the cross-section for top–antitop production has been measured and found to be consistent with the predictions of the Standard Model. The first searches for new phenomena have also been performed, but unfortunately with no sign of unexpected behaviour. In all, the early results presented at the conference were very encouraging and everyone is looking forward to more data being delivered and analysed.

At the same time, the LHC collaborations have continued to extract interesting new physics from the collider's first long run. According to the confinement paradigm of quantum chromodynamics, the gauge theory of strong interactions, only bound states of quarks and gluons that transform trivially under the local symmetries of this description are allowed to exist in nature. It forbids free quarks and gluons, but allows bound states composed of two, three, four, five, etc, quarks and antiquarks, and provides no reason why such states cannot exist. While quark–antiquark and three-quark bound states have been known since the first formulation of the basic theory some 40 years ago, it is only a year or so since unambiguous evidence for tetraquark states was first presented. Now, at EPS-HEP 2015, the LHCb collaboration reported on the observation of exotic resonances in the decay products of the Λ_b, which could be interpreted as charmonium-pentaquarks. The best fit of the findings requires two pentaquark states with spin-parity $J^P = \frac{3}{2}^-$ and $J^P = \frac{5}{2}^+$, although other assignments and even a fit in terms of merely one pentaquark are also possible (*CERN Courier* September 2015 p5).

The study of semileptonic decays of B mesons with τ leptons in the final state offers the possibility of revealing hints of "new ▷

A parallel session in the university's large festival hall.

A poster session in the arcades.

All about communication

The EPS-HEP 2015 conference made several innovations to communicate not only to the participants and particle physicists elsewhere, but also to a wider general public.

Each morning the participants were welcomed with a small newsletter containing information for the day. During the first part of the conference with only parallel sessions, the newsletter summarized the topics of all of the sessions, highlighting expected new results. The idea was to give the participants a glimpse of the topics being discussed at the parallel sessions they could not attend. For the second part of the conference with plenary presentations only, the daily newsletter also contained interviews that looked behind the scenes. The conference was accompanied online in social media, with tweets, Facebook entries and blogs highlighting selected scientific topics and social events. The tweets, in particular, attracted a large audience of people who were not able to attend the conference.

During the first week, a dedicated parallel session on education and outreach took place – the first ever at an EPS-HEP conference. The number of abstracts submitted for the session was remarkable, clearly indicating the need for exchange and discussions on this topic. The conveners chose a slightly different format from the standard parallel sessions, so that besides oral presentations on specific topics, a lively panel discussion with various contributions from the audience also took place. The session concluded with a "Science Slam" – a format in which scientists give short talks explaining the focus of their research in lively terms for the public. Extending the scope of the EPS-HEP conference towards topics concerned with education and outreach was clearly an important strength of this year's edition.

In addition, a rich outreach programme formed an important part of the conference in Vienna; from the start, everyone involved in planning had a strong desire to take the scientific questions of the conference outside of the particle-physics community. One highlight of the programme was the public screening of the movie *Particle Fever*, followed by a discussion with Fabiola Gianotti, who will be the next director-general of CERN, and the producer of the movie, David Kaplan. Visual arts have become another important way to bring the general public in touch with particle physics, and several exhibitions, reflecting different aspects of particle physics from an artistic point of view, took place during the conference.

physics" sensitive to non-Standard Model particles that preferentially couple to third- generation fermions. The BaBar experiment at SLAC, the Belle experiment at KEK and the LHCb experiment at CERN have all observed an excess of events for the B-meson decays $\bar{B}\to D+\tau^-+\bar{\nu}_\tau$ and $\bar{B}\to D^*+\tau^-+\bar{\nu}_\tau$. Averaging over the results of the three experiments, the discrepancy compared with Standard Model expectations amounts to some 3.9σ.

Nonzero neutrino masses and associated phenomena such as neutrino oscillations belong to what is currently the least well-understood sector of the Standard Model. The Tokai to Kamioka (T2K) experiment, using a ν_μ beam generated at the Japan Proton Accelerator Complex situated approximately 300 km east of the Super-Kamiokande detector, was the first to observe ν_μ to ν_e oscillations. It has also made a precise measurement of the angle θ_{23} in the Pontecorvo–Maki–Nakagawa–Sakata neutrino-mixing matrix, the leptonic counterpart of the Cabibbo–Kobayashi–Maskawa (CKM) quark-mixing matrix. However, as this value is practically independent of the relative magnitudes of the neutrino masses, it does not enable the different scenarios for the neutrino-mass hierarchy to be distinguished. A comparison of neutrino oscillations with those of antineutrinos might provide clues to the still unsolved puzzle of charge-parity violation. In this context, T2K presented an update of their earlier results on $\bar{\nu}_\mu$ disappearance results and three candidates for the appearance of $\bar{\nu}_e$.

At the flavour frontier, the LHCb collaboration reported a new exclusive measurement of the magnitude of the CKM matrix element $|V_{ub}|$, while Belle revisited the CKM magnitude $|V_{cb}|$. In the case of $|V_{ub}|$, based on Λ_b decays, there remains a tension between the values distilled from exclusive and inclusive decay channels that is still not understood. For $|V_{cb}|$, Belle presented an updated exclusive measurement that is, for the first time, completely consistent with the inclusive measurement of the same parameter.

Weak gravitational lensing provides a means to estimate the distribution of dark matter in the universe. By looking at more than a million source galaxies at a mean co-moving distance of 2.9 Gpc (about nine thousand million light-years), the Dark Energy Survey collaboration has produced an impressive map of both luminous and dark matter, exhibiting potential candidates for superclusters and (super)voids. The mass distribution deduced from this map correlates nicely with the "known", that is, optically detected, galaxy clusters in the foreground.

Left to right: Thomas Lohse, chair of the EPS High Energy and Particle Physics Division, with winners of the 2015 High Energy and Particle Physics Prize, Guido Altarelli, Lev Lipatov, Yuri Dokshitzer and Giorgio Parisi.

Participants gather for the conference dinner, in the orangery of the Schönbrunn Palace, a World Cultural Heritage site.

More than a year ago, the BICEP2 collaboration caused some disturbance in the scientific community by claiming to have observed the imprint of primordial gravitational waves, generated during inflation, in the B-mode polarization spectrum of the cosmic-microwave background. Since then, the Planck collaboration has collected strong evidence that, upon subtraction of the impact of foreground dust, the BICEP2 data can be explained by a "boring ordinary" cosmic-microwave background (*CERN Courier* November 2014 p15).

Following the parallel sessions that formed the first part of the conference, Saturday afternoon was devoted to the traditional special joint session with the European Committee for Future Accelerators (ECFA). The comprehensive title for this year was "Connecting Scales: Bridging the Infinities", with an emphasis on particle-physics topics that influence the evolution of the universe. This joint EPS-HEP/ECFA session, which was well attended, gave the audience a unique occasion to profit from broad overviews in various fields.

Prizes and more

As is traditional, the award of the latest prizes of the EPS High Energy and Particle Physics Division started the second half of the conference, which is devoted to the plenary sessions. The 2015 High Energy and Particle Physics Prize was awarded to James Bjorken "for his prediction of scaling behaviour in the structure of the proton that led to a new understanding of the strong interaction", and to Guido Altarelli, Yuri Dokshizer, Lev Lipatov and Giorgio Parisi "for developing a probabilistic field theory framework for the dynamics of quarks and gluons, enabling a quantitative understanding of high-energy collisions involving hadrons". The 2015 Giuseppe and Vanna Cocconi Prize was awarded to Francis Halzen "for his visionary and leading role in the detection of very-high-energy extraterrestrial neutrinos, opening a new observational window on the universe". The Gribov Medal, Young Experimental Physicist Prize, and Outreach Prize for 2015 were also presented to their recipients, respectively, Pedro Vieira, Jan Fiete Grosse-Oetringhaus and Giovanni Petrucciani, and Kate Shaw (*CERN Courier* June 2015 p27).

An integral part of every conference is the social programme, which offers the local organizers the opportunity to present impressions of the city and the country where the conference is being held. Vienna is well known for classical music, and on this occasion the orchestra of the Vienna University of Technology performed Beethoven's 7th symphony at the location where it was first performed – the Festival Hall of the Austrian Academy of Sciences. The participants were also invited by the mayor of the city of Vienna to a "Heurigen" – an Austrian wine tavern where recent year's wines are served, combined with local food. A play called *Curie_Meitner_Lamarr_indivisible* presented three outstanding women pioneers of science and technology, all of whom had a connection to Vienna. A dinner in the orangery of the Schönbrunn Palace, the former imperial summer residence, provided a fitting conclusion to the social programme of this important conference for particle physics.

● EPS-HEP 2015 was jointly organized by the High Energy and Particle Physics Division of the European Physical Society, the Institute of High Energy Physics of the Austrian Academy of Sciences, the University of Vienna, the Vienna University of Technology, and the Stefan-Meyer Institute of the Austrian Academy of Sciences. For more details and the full programme, visit http://eps-hep2015.eu/.

Résumé

Valse de particules à Vienne

Les premiers résultats obtenus à une nouvelle frontière des hautes énergies ont été l'un des temps forts de l'édition 2015 de la Conférence sur la physique des hautes énergies de la Société européenne de physique (EPS-HEP). La conférence biennale s'est tenue à Vienne du 22 au 29 juillet, quelques semaines seulement après le début de l'acquisition de données au LHC du CERN à l'énergie dans le centre de masse record de 13 TeV. Outre l'actualité du LHC, les 723 participants, venus du monde entier, ont pu échanger les dernières nouvelles dans différents domaines de la physique des particules et des astroparticules. Une session a été consacrée spécialement à l'éducation et à la communication grand public – une première pour la conférence EPS-HEP.

Wolfgang Lucha and **Jochen Schieck**, Institute for High Energy Physics of the Austrian Academy of Sciences.

Faces & Places

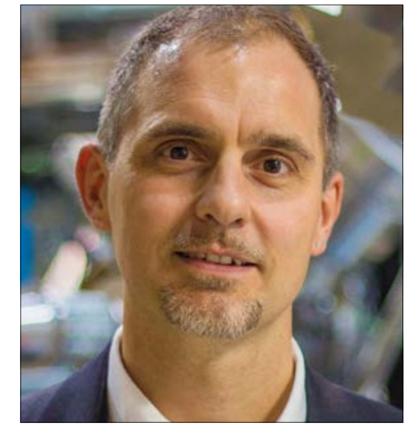
APPOINTMENT

Reiner Kruecken named TRIUMF deputy director

Reiner Kruecken, TRIUMF Science Division head since February 2011, has recently been named deputy director of the laboratory, effective from 1 August 2015. In his new role, Kruecken will support TRIUMF director Jonathan Bagger to develop and manage the laboratory's long-term vision, as well as manage cross-divisional aspects of the ongoing scientific programme, as set out in the most recent five-year plan.

Kruecken has brought to TRIUMF worldwide expertise in nuclear physics, with a deep familiarity with rare-isotope beam facilities in the US, Europe and Asia. His research interests include nuclear structure, reactions and astrophysics; hadron properties in hot, dense nuclear matter; detector developments; biological and medical applications of nuclear methods; particle-induced light emission in dense gases and liquids; and the transmutation of nuclear waste. He earned his PhD in nuclear physics from the University of Cologne, and worked at the Lawrence Berkeley National Laboratory and at the Wright Nuclear Structure Laboratory at Yale, before moving to Technische Universität München in 2002, where he led a large group of researchers as part of the federal cluster of excellence on "Origins and structure of the universe".

The search has begun to fill the (renamed) position of TRIUMF associate lab director of physical sciences.



Reiner Kruecken. (Image credit: TRIUMF.)

OUTREACH

Accelerator showcase inspires the young

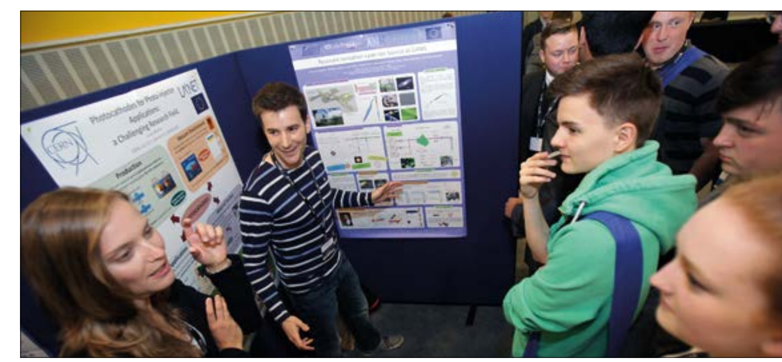
The international Symposium on Lasers and Accelerators for Science and Society, attracting a capacity audience at the Liverpool Arena Convention Centre, took place on 26 June. The event was a sell-out, with delegates comprising 100 researchers from across Europe and 150 local A-level students and teachers. The aim was to inspire young people about science, and the application of lasers and accelerators in particular. "Discovering the unknown", "innovation", "beating cancer", "pioneering new technology" and "a possible career" – these were comments from some of the students.

The symposium included talks from experts in the field such as Victor Malka of the Laboratoire d'Optique Appliquée, Ralph Aßmann of DESY and Brian Cox of the University of Manchester, best known for his television programmes about the origins of the universe. Graham Blair, executive director, programmes, at the UK's Science and Technology Facilities Council, explained the range of science in which accelerators now have a key role. In addition, to research at the high-energy frontier of CERN's LHC, accelerator science has applications across all sectors of industry and healthcare from, for example, measuring strain in jet engines to the accurate targeting of cancerous tumours

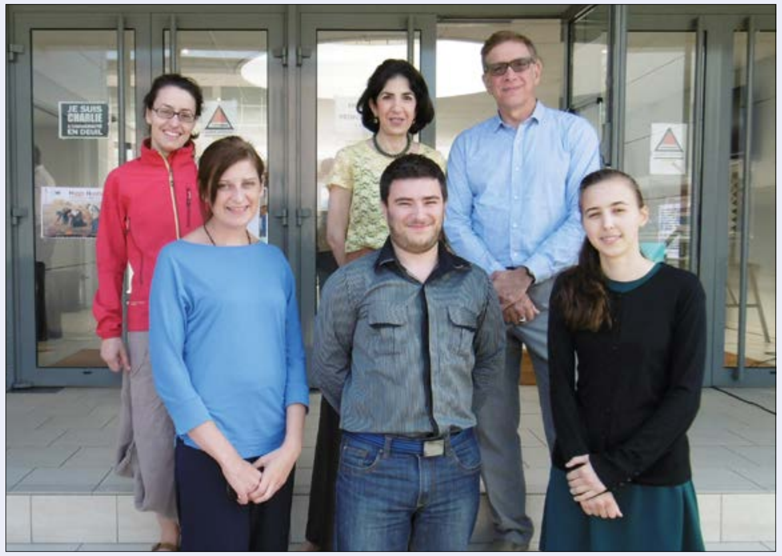
The event also showcased a portfolio of projects by researchers at the forefront of this exciting field of science and engineering, through an interactive poster session with questions and answers. This gave young people the opportunity to see how scientists only a few years older are pushing back the boundaries of knowledge.

The event was organized by Carsten Welsch, head of the Liverpool Accelerator Physics Group at the Cockcroft Institute in Daresbury, who leads two pan-European training networks that aim to address the skills shortage in accelerator science – oPAC (Optimization of Particle Accelerators) and LA^{3}NET (Lasers for Applications at Accelerators). Research fellows in these networks become experts in their discipline and also develop skills in physics, engineering, information technology, data analysis and project management. The involvement of partners from industry and academia and the opportunity to work at research institutions across Europe has provided training that would have been impossible by one company or one country alone.

● Share the enthusiasm through the online presentations available at http://www.liv.ac.uk/quasar/events/outreach_events/symposium/.



A busy poster session. (Image credit: University of Liverpool/STFC.)



Around 140 physicists met in Orsay on 30 July–1 August for the 6th Higgs Hunting Workshop. They discussed the future analyses for LHC Run 2, as well as detailed studies with data from Run 1 on the boson discovered three years ago by ATLAS and CMS, and on possible deviations from the properties predicted by the Standard Model. Searches for additional bosons, prospects with future accelerators, and recent theoretical developments were also covered. Among those attending were Fabiola Gianotti and Joe Incandela, back row centre and right, the two former spokespersons of ATLAS and CMS, respectively, who announced the discovery on 4 July 2012. Eleni Mountricha, back left, and Nansi Andari, front left, passed their thesis examination only a few weeks after the discovery, while Christophe Goudet, front centre, and Julie Rode, front right, are two newcomers in the field. (Image credit: L Fayard.)

Publishing

SCOAP³ delivers open access in high-energy physics

Representatives from all over the world met recently at CERN to discuss the continuation of the SCOAP³ collaboration. (Image credit: SCOAP³ Collaboration.)

Since starting in January 2014, the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP³) has allowed more than 7000 articles on high-energy physics to be published as "open access" at no cost to authors. These articles are accessible to anyone to read and re-use, and their copyright stays with their authors, meeting the expectations of an increasing number of funding agencies and policy makers for open access.

Initiated and hosted at CERN, SCOAP³ is a global collaboration of about 3000 university libraries, library consortia, research organizations and funding agencies. Working with leading publishers, SCOAP³ has converted key high-energy physics journals to open access, without any changes for authors. SCOAP³ pays participating publishers centrally for the costs of open access, and the publishers in turn eliminate or reduce subscription fees for these journals to libraries worldwide. As a result, all final versions of peer-reviewed articles, published in the participating journals, are available immediately and free-of-charge to the entire scientific community, by reusing already existing funds formerly spent on subscriptions.

Each of the 46 participating countries and intergovernmental organizations contributes to a common fund at a level commensurate with its scientific output in high-energy physics. SCOAP³ journals are open for any scientist to publish in, and more than 18,000 individual authors have benefited from free open-access conditions.

Membership of SCOAP³ has grown by more than 50% during the past year, and the SCOAP³ governing bodies together with CERN are now preparing for the continuation of this successful open-access initiative beyond its first three-year period. Scientists will continue to enjoy the advantages of open access at no cost and with no administrative burden, thanks to the support of their libraries and institutions.

● Journals participating in SCOAP³ are: *Acta Physica Polonica B*, *Advances in High Energy Physics*, *Chinese Physics C*, *European Physical Journal C*, *Journal of Cosmology and Astroparticle Physics*, *Journal of High Energy Physics*, *New Journal of Physics*, *Nuclear Physics B*, *Physics Letters B*, *Progress of Theoretical and Experimental Physics*. For more information, visit http://scoap3.org/.

Hungary

LEP cavity takes pride of place at Wigner RCP

On 30 July, CERN's director-general, Rolf Heuer, inaugurated a special exhibit at the Wigner Research Centre for Physics (Wigner RCP) in Budapest – a high-frequency accelerator cavity used in CERN's Large Electron–Positron (LEP) collider. After the ceremony, Heuer visited the high-energy physics laboratories of the Wigner RCP, where different projects for the LHC upgrade programme have begun, as well as the Wigner Datacenter, where CERN's parallel Tier-0 unit is operated by the Wigner RCP (*CERN Courier* July/August 2015 p7). An extension of the Tier-0 host service contract had been signed a few weeks previously.

CERN had donated the LEP cavity to the Wigner RCP last year as part of Hungary's celebrations for CERN's 60th anniversary. Among other CERN 60 events in Hungary, the Colourful Physics Bus ("Boson Bus") – a travelling exhibition – started its roadshow in April 2014, visiting cities, universities and high schools to introduce the latest results on "Higgs hunting" and related investigations in particle physics. Flyers, books and articles were distributed at the various locations. Later in the year, at the CERN-Wigner Open Days in September, some 1000 visitors were guided between tents presenting current experiments at CERN and related Hungarian activities. The visitors could also enjoy a virtual visit to the CMS underground area at CERN, as well as an actual visit to the Wigner Datacenter.

Top: The LEP cavity outside the Wigner RCP, with CERN's director-general, Rolf Heuer, second from right, and Péter Lévai, director-general of the Wigner RCP. (Image credit: Wigner RCP.)

Obituaries

Daniel Kastler 1926–2015

Daniel Kastler, a well-known theoretical physicist at the University of Aix-Marseille, passed away on 4 July, in his 89th year.

Daniel was born on 4 March 1926. His father, Alfred Kastler, was a prominent physicist, awarded the Nobel prize in 1966. After entering the Ecole Normale Supérieure in Paris as a student in 1946, Daniel was ranked first in the agrégation diploma in mathematics in 1949. He went on to become lecturer at the Saarland International University in 1950. Three years later, he became associate professor in mathematics at the same university and received his PhD in quantum chemistry. His doctoral study was a remarkable piece of work in which the whole computation of the diatomic HF molecule was carried out for the first time. In 1957, he joined the University of Aix-Marseille as associate professor, and was appointed full professor in 1959.

In the mid-1950s, Daniel was among those who noticed the link between second quantization and multilinear algebra over Hilbert spaces. As a participant at the famous 1957 Lille Conference, he started to develop the algebraic approach to quantum field theory (AQFT), in collaboration with Rudolf Haag. This culminated in the formulation of the "Haag–Kastler axioms" in 1964, and the concept of "Haag–Kastler–Ruelle local observables"; these are among the most fascinating gems of mathematical physics.

Developing the promising direction of AQFT, further fruitful collaborations emerged, mainly with Sergio Doplicher, Richard Kadison and Derek Robinson, on the one hand, and with Ola Bratelli, Huzihiro Araki, Masamichi Takesaki, Alain Guichardet, Michel Sirugue and Mohammed Mebkhout, on the other. Daniel and collaborators showed the relevance of C*-algebras in the foundation of quantum statistical mechanics (e.g. KMS states, invariant states, temperature states, equilibrium states and ergodic states) and in the study of abelian asymptotic systems.

Daniel Kastler. (Image credit: Ulli Schücker.)

Constantly abreast of the latest trends in C*-algebras and their consequences, from the mid-1980s, Daniel became very enthusiastic about Alain Connes' non-commutative geometry and its applications to fundamental interactions, in particular as a new approach to the Standard Model and the Higgs boson. As one of its leading and most fervent supporters, Daniel contributed substantially to promoting Connes' viewpoint. In the meantime, with Raymond Stora, he provided a geometrical setting of the important BRST transformations for quantizing gauge theories.

With his stimulating enthusiasm, Daniel carried in his wake several collaborators, including Jean Bellisard, Daniel Testard, Robert Coquereaux, Arkadiusz Jadczyk, John Madore, Thomas Schücker, Bruno Iochum, Peter Seibt, Thierry Masson, Thomas Krajewski and, his last PhD student, Koumarane Valavane. His last research quest in the early 2000s was, in his own words, to "fish out the salmon among the medusa" with the help of a quantum group at the root of unity. He also had in mind a book project – several chapters should still be on the hard disk of his computer – as his scientific legacy.

Daniel was not only a great scientist at the boundary between mathematics and physics, he also sought constantly to attract research experts to Marseilles to develop these streams of ideas in France and build leadership potential. He also had a humanist vision. He was one of the three co-founders, in 1968, of the Centre de Physique Théorique (CPT) in Marseilles, together with Jean-Marie Souriau and Antoine Visconti. He helped a great deal in the creation of the Luminy Institute of Mathematics at Aix-Marseille to bring together theoretical physicists and mathematicians at the same place. He also contributed much to create a main hub between mathematicians and mathematical physicists in the Marseilles area. To the east, beyond the so-called "University of Bandol" – his own place where he brought several scientific guests, driving them by car on the coast road past the impressive cliffs of Cassis – he was involved in the creation of the mathematical physics team at the University of Toulon.

Many of us owe much to Daniel's foundational efforts in Marseilles, and we wish to pay tribute to his fighting spirit, his open-mindedness and his ability. We will also remember his humanity, his kindness and his humour. He was passionate about music, including the piano, and loved poetry. In the words of Jean-Claude Risset, physicists and musician, Daniel had "a profound sense of the essential role of beauty in science and in life".

All of the great scientific and human qualities that Daniel was able to share and transmit were mainly thanks to the strong and unfailing support of his beloved wife, Liesl.

● *Thierry Martin and Serge Lazzarini, CPT management team, and Pierre Chiappetta, former CPT director. This obituary is also published in the July issue of the Bulletin of* the International Association of Mathematical Physics (*http://www.iamp.org*).

Boris Zupnik 1945–2015

Boris Zupnik, an eminent Russian theorist who was a leading researcher at the Bogoliubov Laboratory of Theoretical Physics (LTP) of JINR in Dubna and professor at Dubna University, passed away on 20 March after a few months of serious illness.

Boris Zupnik was born on 12 June 1945 in Samarkand, Uzbekistan, where his Jewish family had been evacuated from Dniepropetrovsk, Ukraine, in 1941. Following the war, the family returned to their city, and Boris went on to graduate from the Dniepropetrovsk State University in 1968. He then joined the LTP in Dubna as a postgraduate. At the time his supervisor, Victor Isaakovich Ogievetsky, was interested in chiral dynamics, a new approach to low-energy strong interactions. Together with Ogievetsky, Boris obtained first-class results in the field. He stood out as a promising young researcher with solid mathematical background and a deep sense for the beauty of theoretical physics.

In 1972, Boris brilliantly defended his PhD thesis, but despite the best efforts of his supervisor, he was not admitted to the LTP staff. He spent the next 20 years as a researcher at the Institute of Nuclear Physics in Ulugbek near Tashkent, and as a lecturer at the Tashkent State University. There, he continued his research and taught several talented PhD students.

Boris maintained his close contacts with Ogievetsky's group at the LTP, where supersymmetry became the centre of interest. The superfield approach to super-Yang–Mills and supergravity became, for Boris, his favorite research topic. He made a particularly significant contribution to the new harmonic superspace method

Boris Zupnik. (Image credit: V Zupnik.)

developed in Dubna in the early 1980s, and was among the first to generalize it to other dimensions. One of his most striking results was the beautiful closed form for the harmonic superspace action of the N = 2, 4D (or N = (1,0), 6D) super-Yang–Mills theory. It is now called "Zupnik's action".

After defending his habilitation thesis in Dubna in 1991, Boris finally joined the LTP in 1994 – by then named after Nicolai Bogoliubov – and successfully continued his investigations of superfield theories in diverse dimensions. His main achievements are the N = 3 Born–Infeld theory, and the new superfield formulations of the superconformal N = 3, 6, 8 Chern–Simons theories, among others. In the last year of his life, Boris kept searching for the ultimate off-shell formulation of the renowned N = 4 super-Yang–Mills theory. This challenging problem – still unsolved – was always among his top research priorities.

Boris had a warm and friendly personality, always open to new ideas. He chose his research topics independently and wrote many excellent papers without co-authors. He was also a very modest person, with scientific and moral authority among theoreticians worldwide. He spent much time educating young physicists at the International University in Dubna. He was very dedicated to his family, and a respected father and grandfather.

The death of Boris Zupnik is a great loss for his friends and colleagues, and for the whole world of theoretical physics.

● *Friends and colleagues of Boris.*

Letter

First names in modern physics

In his book review in praise of Oskar Klein (*CERN Courier* July/August 2015 p49), Johann Rafelski paraphrased Alan Guth's words as "how many recognize Oskar as the first name of 'this' Klein? Compare here (by birth year, within 10 years): Niels B (1885), Hermann W (1885), Erwin S (1887), Satyendra N B (1894), Wolfgang P (1900), Enrico F (1901), Werner H (1901), Paul A M D (1902), Eugene W (1902), Robert O (1904). Thanks to this book, Oskar K (1894) will take his place on this short list."

I think that Louis de B (Louis de Broglie, born 1892) and George G (George Gamow, 1904) were missed out in this list of luminaries. Moreover, the following are worth including if Guth's birth-year criterion is extended by plus or minus five years: Max B (Max Born, 1882), Emmy N (Emmy Noether, 1882), Lev L (Lev Landau, 1908), Sin-Itiro T (Sin-Itiro Tomonaga, 1906), Hideki Y (Hideki Yukawa, 1907) and Hendrik C (Hendrik Casimir, 1909).

● *Min-Liang Wong, Department of Veterinary Medicine, National Chung-Hsing University, Taichung, Taiwan.*

New products

EDAX Inc. has announced the addition of a new series of Octane Elite silicon drift detectors (SDD) to its existing portfolio of detectors. The Octane Elite SDD Series offers an up to 35% improvement in light-element sensitivity and outstanding low-energy performance, owing to the use of silicon-nitride (Si_3N_4) entry windows, which replace the polymer windows that have been standard since the inception of SDD technology. For further details, contact Sue Arnell, e-mail sue.arnell@ametek.com or visit www.edax.com.

Goodfellow offers a selection of polymer films, including specialist products suitable for demanding applications. Among these special polymer films are: polyphenylenesulphide (PPS) in thicknesses from 0.1 to 0.4 mm, polyetherimide (PEI) in thicknesses from 0.025 to 0.50 mm, and polyetherketone (PEK) in thicknesses from 0.040 to 0.100 mm. In addition to film, Goodfellow can supply many polymers as rods, sheets, tubes, granules, fabric, fibre, monofilament, honeycomb and fasteners (nuts, bolts, washers). For more information, email info@goodfellow.com or visit goodfellow.com.

Siemens has expanded its portfolio of rugged network components with the Ruggedcom RMC8388 – a compact time converter designed to operate in harsh environments with widely varying climatic and environmental conditions. Withstanding extreme temperatures from –40 up to +85 °C, vibration and shock, the device offers high reliability for electric-power applications. By enabling cost-effective time synchronization, Ruggedcom RMC8388 also reduces capital expenditures and maintenance costs. For further information, visit www.siemens.com/rmc8000.

Spectrum Systementwicklung GmbH, has released a Digitizer Handbook, available free of charge, which provides answers to questions about functionality, performance and the application of digitizers. Topics include how to select a digitizer, understanding the various terms, and comparing performance with other instruments, such as digital oscilloscopes. It also explains the structure of device drivers and how cards can be programmed using popular programming languages such as Visual C++, Borland C++, Gnu C++, Visual Basic and Python. To request a copy, visit www.spectrum-instrumentation.com/contact-us.

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.

GUINA ENERGY GROUP

RELOCATE TO AUSTRALIA

OUTSTANDING OPPORTUNITY FOR
SUPERCONDUCTING COIL WINDING TECHNICIAN

SALARY UP TO AU$110,000 PLUS RELOCATION EXPENSES

Guina Energy Technologies Pty Ltd is an Australian company specialising in applied research and development in electromagnetic rotating machines.

Our company employs a close knit professional staff of 13 committed to the company's pursuit of advanced alternative energy solutions.

Our company requires an experienced Superconducting Coil Winding Technician to perform and oversee the physical construction of superconducting coil packs used in our novel superconducting motor and generator technology. The successful applicant will possess:

- Proven, hands on experience in the winding and construction of low and high temperature superconducting coil assemblies;
- Extensive experience in the selection, adaptation, setup and calibration of coil winding machinery to wind superconducting coils, and;
- Extensive experience in the physical construction and manufacture of superconducting magnets.

It is envisaged that other appointments under the daily direction of the successful candidate will follow as the company's activities expand. Superconducting coil winding project management experience whilst not essential would be advantageous.

This is an autonomous role within a collaborative and collegiate team.

In addition to the above core requirements, experience with superconducting motors/generators and rotating machinery will be favourably considered.

The position is located at the company's laboratory facilities on the Gold Coast, Queensland, Australia, one hours drive south of Brisbane. The successful applicant will be required to relocate to the Gold Coast. The successful applicant will be rewarded with an attractive salary package inclusive of statutory superannuation up to AU$110,000 commensurate with skills and experience, a modern and well equipped work environment, an agreed reimbursement of relocation expenses for the applicant and their family and a relaxed eastern Australia coastal lifestyle.

Applications close 30 September 2015.

If you are confident of satisfying the above requirements, please forward your resume to Andrew Budd, General Manager at **andrew@guinaenergy.com**

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

ACCELERATOR CONTROLS.

DESY, Hamburg location, is seeking:
Scientist (f/m) Software Architect

DESY
DESY is one of the world's leading research centres for photon science, particle and astroparticle physics as well as accelerator physics.

The group MCS runs, maintains and develops the control systems of all accelerators operated by DESY. The MCS accelerator control systems implement a multi-layer, distributed and network-based system architecture. The MCS team develops accelerator-specific system and application software based on various programming languages and operation systems.

The position
- Participation in further development and maintenance of existing accelerator control systems at DESY
- Participation in development of novel concepts for accelerator control systems
- Leading role in daily operations

Requirements
- Graduate degree (Physics, Computer Science or similar fields)
- Highly advanced and up-to-date programming skills (C/C++, Java)
- Highly advanced knowledge of IT-systems
- Longtime experiences in the field of accelerator control or industrial process control systems
- Teamwork ability
- Willingness to take responsibility

For further information please contact Mr Reinhard Bacher +49-40-8998-3056.

Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. DESY operates flexible work schemes. Handicapped persons will be given preference to other equally qualified applicants. DESY is an equal opportunity, affirmative action employer and encourages applications from women. There is a bilingual kindergarten on the DESY site.

We are looking forward to your application quoting the reference code preferably via our electronic application System: Online-Application or by email recruitment@desy.de
Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: EM120/2015
Notkestraße 85 | 22607 Hamburg | Germany | Phone: +49 40 8998-3392
Deadline for applications: 15 November 2015
www.desy.de

The Helmholtz Association is Germany's largest scientific organisation.
www.helmholtz.de

HELMHOLTZ | ASSOCIATION

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

COLLIDER PHENOMENOLOGY.

DESY, Hamburg location, is seeking:
Scientist (f/m) Collider Phenomenology

DESY
DESY is one of the world's leading research centres for photon science, particle and astroparticle physics as well as accelerator physics.

The DESY theory group pursues a vigorous research programme in the investigation of the fundamental interactions of nature and the fabric of matter, space and time. In particular, possible manifestations of TeV-scale physics at the Large Hadron Collider (LHC), at other existing facilities and at a future Linear Collider are studied in close interaction with experiment and with activities in particle cosmology, lattice gauge theory and string theory.

The position
- Engage in research on collider phenomenology at an internationally competitive level, with a particular focus on physics beyond the standard model
- Participate in the activities of the DESY theory group
- Show active engagement with experimental groups

Requirements
- Ph. D. in physics
- Excellent research record and international reputation in the area of particle physics phenomenology
- Team ability and very good English language skills

For further information please contact Prof. Dr. Georg Weiglein, georg.weiglein@desy.de.

Please submit your application including the usual documents in English (curriculum vitae, research statement, publication list and copies of university degrees) to the DESY human resources department.

Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. DESY operates flexible work schemes. Handicapped persons will be given preference to other equally qualified applicants. DESY is an equal opportunity, affirmative action employer and encourages applications from women. There is a bilingual kindergarten on the DESY site.

We are looking forward to your application quoting the reference code preferably via our electronic application System: Online-Application or by email recruitment@desy.de
Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: EM143/2015
Notkestraße 85 | 22607 Hamburg | Germany | Phone: +49 40 8998-3392
Deadline for applications: 25 October 2015
www.desy.de

The Helmholtz Association is Germany's largest scientific organisation.
www.helmholtz.de

HELMHOLTZ | ASSOCIATION

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

The **Heidelberg Graduate School of Fundamental Physics (HGSFP)** at the Department of Physics and Astronomy at Heidelberg University, a School funded by the German Excellence Initiative, invites applications for

DOCTORAL FELLOWSHIPS

in the following areas of modern fundamental physics: (a) Astronomy and Cosmic Physics, (b) Quantum Dynamics and Complex Quantum Systems, (c) Fundamental Interactions and Cosmology, (d) Complex Classical Systems, (e) Mathematical Physics, and (f) Environmental Physics. Thesis research topics cover areas such as experimental and theoretical astrophysics, cosmology, accelerator based particle physics, precision measurements in physics, study of quantum systems – many body as well as small systems, low as well as high temperature physics, atomic, molecular and optical physics, mathematical physics and string theory. In addition, fundamental problems in biophysics, e.g. in materials science aspects of cell biology, and in environmental physics are studied. The HGSFP combines doctoral projects at the forefront of international research in the areas mentioned above with a rich and thorough teaching programme. Further information can be found on the School's web site: **http://www.fundamental-physics.uni-hd.de**.

The branch Astronomy & Cosmic Physics is the International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics at the University of Heidelberg (**http://www.mpia.de/imprs-hd**). Students accepted into the Graduate School will automatically be members of the IMPRS-HD and conversely. Admission to the IMPRS for Precision Tests of Fundamental Symmetries (**www.mpi-hd.mpg.de/imprs-ptfs**), to the IMPRS for Quantum Dynamics in Physics, Chemistry and Biology (**http://www.mpi-hd.mpg.de/imprs-qd**), to the RTG Particle Physics Beyond the Standard Model (**http://www.thphys.uni-heidelberg.de/~gk_ppbsm**) or the RTG HighRR (High Resolution and High Rate Detectors in Nuclear and Particle Physics) is also possible. The IMPRS and RTGs offer doctoral positions and fellowships as well, and are combined efforts of Heidelberg University with the Max Planck Institutes for Astronomy and Nuclear Physics, which form an integral part of the exciting and broad research environment in Heidelberg.

Highly qualified and motivated national and international students are invited to apply. Applicants should preferably hold a Master of Science or equivalent degree in physics. Excellent candidates holding a four year bachelor degree and proof of research experience may also be considered. At equal level of qualification, preference will be given to disabled candidates. Female students are particularly encouraged to apply.

Applicants have to initiate their application registering via a web form available at **http://www.fundamental-physics.uni-hd.de/fellowships**. Applications should be completed by November 21, 2015.

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

PARTICLE PHYSICS.

DESY, Hamburg location, is seeking:
Scientist (f/m)

DESY
DESY is one of the world's leading research centres for photon science, particle and astroparticle physics as well as accelerator physics.

The particle physics programme of DESY consists of strong contributions to the LHC experiments ATLAS and CMS and to the preparation of future experiments. The experimental programme is enhanced by collaboration with a strong theory group. DESY is searching an experienced high energy experimental physicist (f/m), who will take a leading role in the physics analysis of ATLAS data.

The position
- Active role in the ATLAS experiment
- Leading role in ATLAS data analysis and determination of proton structure functions
- Strong participation in ATLAS detector operation
- Participation in the supervision of students and postdocs

Requirements
- PhD in experimental High Energy Physics
- Extensive knowledge and experience in data analysis
- Experience in detector operations
- Outstanding teamwork abilities and excellent communication skills and knowledge of English

For further information please contact
Dr. Ingrid Gregor
+49-40-8998-3032, ingrid.gregor@desy.de or
Dr. Klaus Moenig
+49-33762-77271, klaus.moenig@desy.de.

Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. DESY operates flexible work schemes. Handicapped persons will be given preference to other equally qualified applicants. DESY is an equal opportunity, affirmative action employer and encourages applications from women. There is a bilingual kindergarten on the DESY site.

We are looking forward to your application quoting the reference code preferably via our electronic application System: Online-Application or by email recruitment@desy.de
Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: EM142/2015
Notkestraße 85 | 22607 Hamburg | Germany |
Phone: +49 40 8998-3392
Deadline for applications: 15 October 2015
www.desy.de

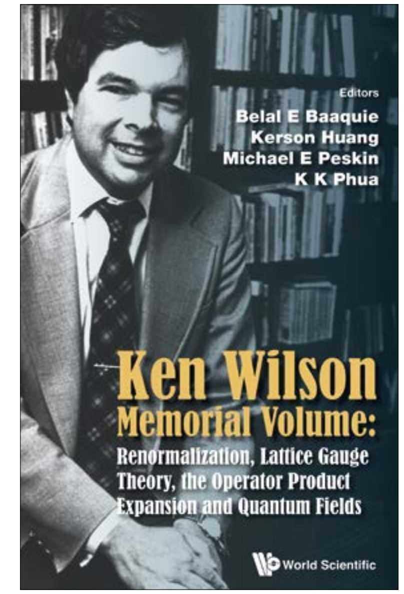
The Helmholtz Association is Germany's largest scientific organisation.
www.helmholtz.de

HELMHOLTZ | ASSOCIATION

Bookshelf

Ken Wilson Memorial Volume: Renormalization, Lattice Gauge Theory, the Operator Product Expansion and Quantum Fields

By Belal E Baaquie et al. *(eds)*
World Scientific
Hardback: £57
Paperback: £29



As the title of this collection of essays on the work of Kenneth Wilson (1936–2013) indicates, his impact on physics was enormous, transforming both high-energy and condensed-matter physics. He also foresaw much of the modern impact of computers and networking, and I can feel that influence even as I type this review.

This is a long book, comprising 385 pages with 21 essays by many of today's most influential physicists. It should be made clear that while it includes plenty of biographical material, this is, for the most part, a combination of personal reminiscences and highly technical articles. A non-physicist, or even a physicist without a fairly deep understanding of modern quantum field theory, would probably find much of it almost completely impenetrable, with equations and figures that are really only accessible to the cognoscenti.

That said, a reading of selected parts sheds interesting light on a variety of complex topics in ways that are perhaps not so easily found in modern textbooks. I would not hesitate to suggest such a strategy to a philosopher or historian of science, or an undergraduate or graduate student in physics. The chapters are all well written, and whatever fraction is understood will prove valuable.

Some of the most interesting parts are quotations from Wilson himself. A particularly striking example is from Paul Ginsparg's essay: "I go to graduate school in physics, and I take the first course in quantum field theory, and I'm totally disgusted with the way it's related. They're discussing something called renormalization group, and it's a set of recipes, and I'm supposed to accept that these recipes work – no way. I made a resolution, I would learn to do the problems that they assigned, I would learn how to turn in answers that they would expect, holding my nose all the time, and some day I was going to understand what was really going on."

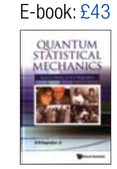
He did, and now thanks to him, we do too. This represents just a fraction of the impact that Wilson has had on our field. The book is long, and not an easy read, but well worth the effort and I highly recommend it.

● *John Swain, Northeastern University.*

Books received

Quantum Statistical Mechanics: Selected Works of N N Bogolubov

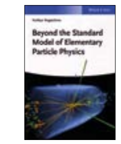
By N N Bogolubov, Jr (ed.)
World Scientific
Hardback: £57
E-book: £43



Nicolai Bogolubov (1909–1992) was well known in the world of high-energy physics as one of the founders of JINR, Dubna, and the first director of the Laboratory Theoretical Physics, now named after him. He was also well known in the wider community for his many contributions to quantum field theory and to statistical mechanics. Part I of this book, which is edited by his son, contains some of the elder Bogolubov's papers on quantum statistical mechanics, a field in which he obtained a number of fundamental results, in particular in relation to superfluidity and superconductivity. Superfluidity was discovered in Russia in 1938 by Kapitza, and in 1947 Bogolubov published his theory of the phenomenon based on the correlated interaction of pairs of particles. This later led him to a microscopic theory for superconductivity, which helped to set the Bardeen–Cooper–Schrieffer theory on firm ground. Part II is devoted to methods for studying model Hamiltonians for problems in quantum statistical mechanics, and is based on seminars and lectures that Bogolubov gave at Moscow State University.

Beyond the Standard Model of Elementary Particle Physics

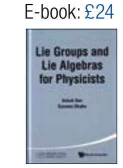
By Yorikiyo Nagashima
Wiley
Hardback: £105 €131.30
E-book: £94.99 €118.80
Also available at the CERN bookshop



This comprehensive presentation of modern particle physics provides a store of background knowledge of the big open questions that go beyond the Standard Model, concerning, for example, the existence of the Higgs boson or the nature of dark matter and dark energy. For each topic, the author introduces key ideas and derives basic formulas needed to understand the phenomenological outcomes. Experimental techniques used in detection are also explained. Finally, the most recent data and future prospects are reviewed. The book can be used to provide a quick look at specialized topics, both to high-energy and theoretical physicists and to astronomers and graduate students.

Lie Groups and Lie Algebras for Physicists

By Ashok Das and Susumo Okubo
World Scientific
Hardback: £63
E-book: £24



Ashok Das and Susumu Okubo, colleagues at the University of Rochester, are theoretical high-energy particle physicists from different generations. Okubo's name is probably best known for the mass formula for mesons and baryons that he and Murray Gell-Mann derived independently through the application of the SU(3) Lie group in the quark model, while Das works on questions related to symmetry. Their book is intended for graduate students of theoretical physics (with a background in quantum mechanics) as well as researchers interested in applications of Lie group theory and Lie algebras in physics. The emphasis is on the inter-relations of representation theories of Lie groups and the corresponding Lie algebras.

Viewpoint

Pakistan: fulfilling Salam's wish

Hafeez Hoorani looks at opportunities for Pakistan, CERN's newest associate member.

Hafeez Hoorani. (Image credit: Muhammad Imran/NCP.)

In September 1954, the European Organization for Nuclear Research – CERN – officially came into existence. This was just nine years after the Second World War, when Europe was completely divided and torn apart. Founders of CERN hoped that "it would play a fundamental role in rebuilding European physics to its former grandeur, reverse the brain drain of the brightest and best to the US, and continue and consolidate post-war European integration". Today, as one of the outstanding high-energy physics laboratories in the world, CERN has not only more than fulfilled the goals of its founders, but is also a laboratory for thousands of physicists and engineers from all over the world.

CERN is a fine example in which high technology and science reinforce both each other and international collaboration. Exploration of the unknown is the hallmark of fundamental research. This requires, on one hand, cutting-edge technology for developing detectors for the LHC, the world's largest accelerator. On the other hand it necessitates new concepts in computer software for the storage and analysis of the enormous amount of data generated by LHC's experiments.

On 31 July, Pakistan officially became an associate member of CERN. There is one respect in which CERN has a very special relationship with Pakistan. Experiments done at CERN in 1973 provided the first and crucial verification of one of the predictions of electroweak unification theory proposed by Sheldon Glashow, Abdus Salam and Steven Weinberg, which resulted in the award of the 1979 Nobel Prize in Physics to these three physicists. In a speech made by Salam on 11 May 1983 in Bahrain, he said: "We forget that an accelerator like the one at CERN develops sophisticated modern technology at its furthest limit. I am not advocating that we should build a CERN for Islamic countries. However, I cannot but feel envious that a relatively poor country like Greece has joined CERN, paying a subscription according to the standard GNP formula. I cannot rejoice that Turkey, or the Gulf countries, or Iran or Pakistan seem to show no ambition to join this fount of science and get their people catapulted into the forefront of the latest technological expertise. Working with CERN's accelerators brings at the least this reward to a nation, as Greece has had the perception to realize." Salam's wish has now been fulfilled.

Pakistan has had an established linkage with CERN for more than two decades. The CERN–Pakistan co-operation agreement was signed in 1994. In 1997, the Pakistan Atomic Energy Commission signed an agreement for an in-kind contribution worth $0.5 million for the construction of eight magnetic supports for the CMS detector. This was followed by another agreement in 2000, where Pakistan assumed responsibility for the construction of part of the CMS muon system, increasing Pakistan's contribution to $1.8 million. Through the same agreement, the National Centre for Physics (NCP) became a full member of the CMS collaboration. In 2004, the NCP established a Tier-2 node in the Worldwide LHC Computing Grid, the first in south-east Asia.

Since then, there has been no looking back. Pakistan has contributed to all of the four big experiments at the LHC, as well as in the consolidation of the LHC accelerator itself. Above all, Pakistani physicists and hardware built in Pakistan for the CMS detector played an important role in the discovery of the Higgs boson in 2012, the last missing piece of the Glashow–Salam–Weinberg model.

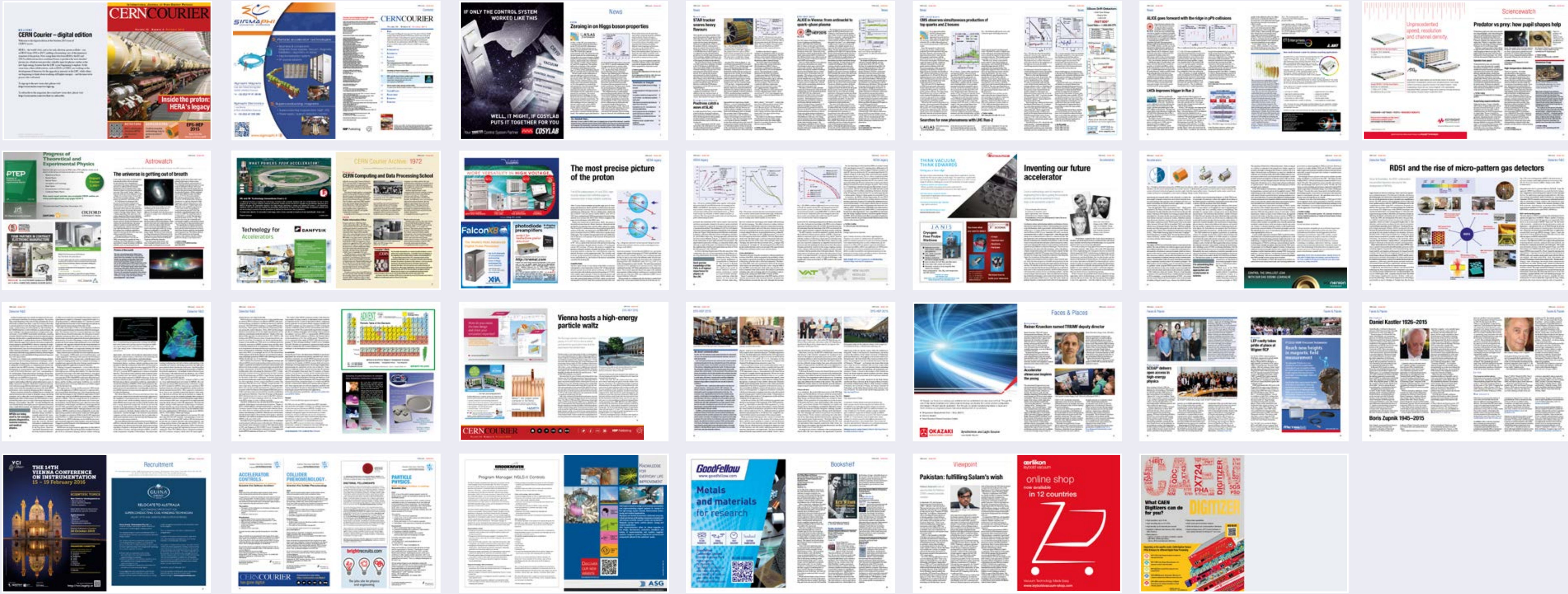
Pakistan's collaboration with CERN has already resulted in numerous benefits: manufacturing jobs in engineering, benefiting Pakistani industry; engineers learning new techniques in design and quality assurance, which in turn improves the quality of engineering in Pakistan; a unique opportunity for interfacing among multidisciplinary groups in academia and industry working at CERN; and working in an international environment with people from diverse backgrounds has advantages of its own.

It is hoped that CERN has also benefited from the expertise brought in by Pakistani scientists, students, engineers and technicians to save time and money. It has certainly been satisfying for Pakistan to contribute in a small way in this great enterprise.

We also plan to get involved in CERN's future research and development projects. In particular, there is keen interest in the Pakistani physics community to participate in R&D for future accelerators. Discussions are already underway to understand where we can contribute meaningfully, keeping in mind our resources and other limitations. In particular, there is strong interest among Pakistani physicists to be involved in the R&D for a future linear collider.

In this new phase of Pakistan–CERN co-operation, which started on 19 December 2014 with the signing of the document for associate membership (*CERN Courier* January/February 2015 p6), the emphasis will shift to finding work opportunities at CERN for young scientists and engineers, as well as to the training of young Pakistani scientists at CERN. It will also be an opportunity for Pakistan to be more deeply involved in fundamental research in physics. For this purpose, we would involve our graduate students in work with physics groups at CERN as a part of their PhD studies. This would provide an opportunity for our young scientists and engineers to contribute to knowledge at the very frontiers of physics.

● *Hafeez Hoorani, director-general of the National Centre for Physics, Pakistan.*



CERNCOURIER

VOLUME 55 NUMBER 8 OCTOBER 2015

Contents

5 **NEWS**

● *Zeroing in on Higgs boson properties* ● *So, farewell then* ● *STAR tracker snares heavy flavours* ● *Positrons catch a wave at SLAC* ● *ALICE in Vienna: from antinuclei to quark–gluon plasma* ● *CMS observes simultaneous production of top quarks and Z bosons* ● *Searches for new phenomena with LHC Run-2* ● *ALICE goes forward with the ridge in pPb collisions* ● *LHCb improves trigger in Run 2*

13 **SCIENCEWATCH**

15 **ASTROWATCH**

17 **ARCHIVE**

FEATURES

19 **The most precise picture of the proton**
H1 and ZEUS release their definitive paper on deep-inelastic scattering.

23 **Inventing our future accelerator**
Could an inventive methodology help to guide the innovate process?

26 **RD51 and the rise of micro-pattern gas detectors**
The RD51 collaboration has provided important stimulus for growth in the development of MPGDs.

33 **Vienna hosts a high-energy particle waltz**
A report from the first major summer conference on particle physics.

37 **FACES&PLACES**

43 **RECRUITMENT**

49 **BOOKSHELF**

50 **VIEWPOINT**