WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the July/August 2013 issue of *CERN Courier*.

This "double issue" provides plenty to read during what is for many people the holiday season. The feature articles illustrate well the breadth of modern particle physics – from the Standard Model, which is still being tested in the analysis of data from Fermilab's Tevatron, to the tantalizing hints of extraterrestrial neutrinos from the IceCube Observatory at the South Pole. A connection of a different kind between space and particle physics emerges in the interview with the astronaut who started his postgraduate life at CERN, while connections between particle physics and everyday life come into focus in the application of particle detectors to the diagnosis of breast cancer. And if this is not enough, take a look at Summer Bookshelf, with its selection of suggestions for more relaxed reading.

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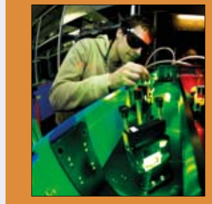
DIGITAL EDITION CREATED BY JESSE KARJALAINEN/IOP PUBLISHING, UK

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERNCOURIER
VOLUME 53 NUMBER 6 JULY/AUGUST 2013

IceCube brings news from the deep



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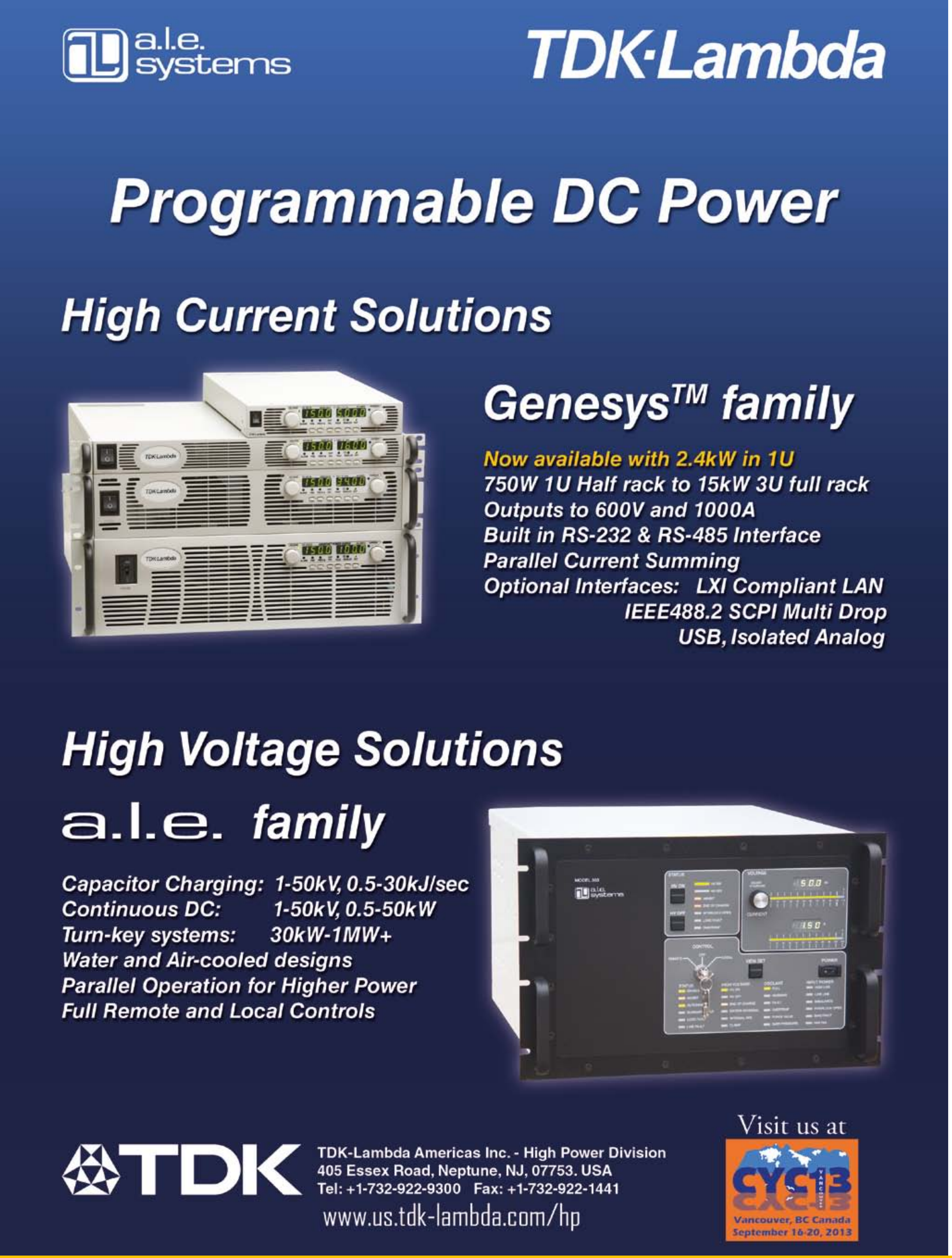

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Covering current developments in high-energy physics and related fields worldwide

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.

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

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General distribution Courrier Adressage, CERN, 1211 Geneva 23, Switzerland
E-mail: courrier-adressage@cern.ch
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China Keqing Ma, Library, Institute of High Energy Physics,
PO Box 918, Beijing 100049, People's Republic of China
E-mail: keqingma@mail.ihep.ac.cn
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UK Mark Wells, Science and Technology Facilities Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1SZ
E-mail: mark.wells@stfc.ac.uk
US/Canada Published by Cern Courier, 6N246 Willow Drive,
St Charles, IL 60175, US. Periodical postage paid in St Charles, IL, US
Fax 630 377 1569. E-mail: creative_mailing@att.net
POSTMASTER: send address changes to: Creative Mailing Services, PO Box 1147,
St Charles, IL 60174, US

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

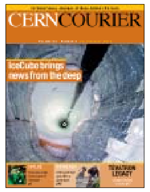
Printed by Warners (Midlands) plc, Bourne, Lincolnshire, UK

 ISSN 0304-288X

IOP Publishing

CERNCOURIER

Volume 53 Number 6 July/August 2013



On the cover: A digital optical module descends down a hole deep in the ice during the installation of the IceCube Neutrino Observatory at the South Pole. IceCube has recently detected neutrinos with record-breaking energies around 1 PeV and observed neutrino oscillations (p5). It also has the potential to seach for exotic physics (p35). (Image credit: NSF/B Gudbjartsson.)

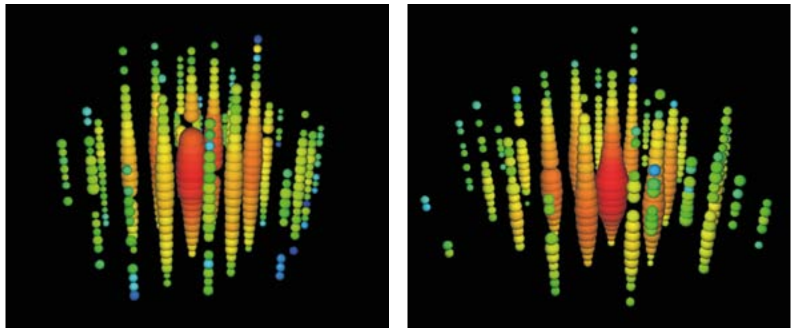
News

Neutrinos

IceCube detects ultra-high-energy events and observes oscillations

Neutrino experiments – thanks to the nature of the particles themselves – are notoriously difficult and experiments that make use of the natural source of particles within the cosmic radiation face problems of their own. In detecting cosmic neutrinos, the IceCube Neutrino Observatory at the South Pole successfully contends with both of these challenges, as two papers to appear in *Physical Review Letters* reveal. They illustrate the observatory's capabilities in particle physics and in astroparticle physics.

The potential for IceCube to meet its aim of detecting neutrinos from astrophysical sources has been boosted by the observation of two neutrino events with the highest energies ever seen. The events have estimated energies of 1.04±0.16 and 1.14±0.17 PeV – hundreds of times greater than the energy of protons at the LHC. The expected number of atmospheric background events at these energies is 0.082±0.004 (stat.)$^{+0.04}_{-0.057}$ (syst.) and the probability that the two observed events are not background is 2.9×10^{-3}, giving the signal a significance of 2.8σ (Aartsen *et al.* 2013a). While this is not sufficient to indicate a first observation of astrophysical neutrinos, the closeness in energy of the two events is intriguing and is already attracting the attention of theorists.



The two observed events from, left, August 2011 and, right, January 2012. Each sphere represents an optical module, where the size is a measure of the recorded number of photo-electrons. Colours represent the arrival times of the photons, where red indicates early and blue late times. (Image credit: IceCube collaboration.)

Meanwhile, measurements of lower-energy neutrinos produced in the atmosphere have enabled the IceCube collaboration to make the first statistically significant detection of neutrino oscillations in the high-energy region (20–100 GeV). The data used for this analysis were collected between May 2010 and May 2011 by the IceCube and DeepCore detectors, which together make up the IceCube Neutrino Observatory (*CERN Courier* March 2011 p28). The IceCube detector consists of an array with 86 strings of digital sensors deployed in Antarctica's ice sheet at depths in the range 1450–2450 m. This main array defines the high-energy detector, designed to detect neutrinos with energies from hundreds to millions of giga-electron-volts – that is, up to the peta-electron-volts and more of the observed high-energy events. The DeepCore subdetector adds eight additional strings near the centre of this array, six of which were deployed during the period covered by this analysis. The denser core allows lowering the energy threshold to about 20 GeV.

The analysis revealed the disappearance of low-energy, upwards-moving muon neutrinos and rejected the non-oscillation hypothesis with a significance of more than 5σ. This result verifies the first, lower-significance indication reported by the ANTARES collaboration. Using a two-neutrino flavour formalism, the IceCube collaboration derived a new estimation of the oscillation parameters, $|\Delta m^2_{23}| = 2.3^{+0.6}_{-0.5}\times10^{-3}\,eV^2$ and $\sin^2 2\theta_{23} > 0.93$, with maximum mixing favoured. These values are in good agreement with previous measurements by the MINOS and Super-Kamiokande experiments.

More efficient event-reconstruction methods are being tested, which together with new data sets will increase the sensitivity of the IceCube and DeepCore detectors to atmospheric neutrino oscillations. As a result of these improvements, the IceCube collaboration is expecting to set further constraints on the oscillation parameters in the coming months.

● Further reading

M G Aartsen *et al.* 2013a arXiv:1304.5356 [astro-ph.HE], accepted by *Phys. Rev. Letts.*
M G Aartsen *et al.* 2013b arXiv:1305.3909 [hep-ex], accepted by *Phys. Rev. Letts.*

Sommaire en français

CERN

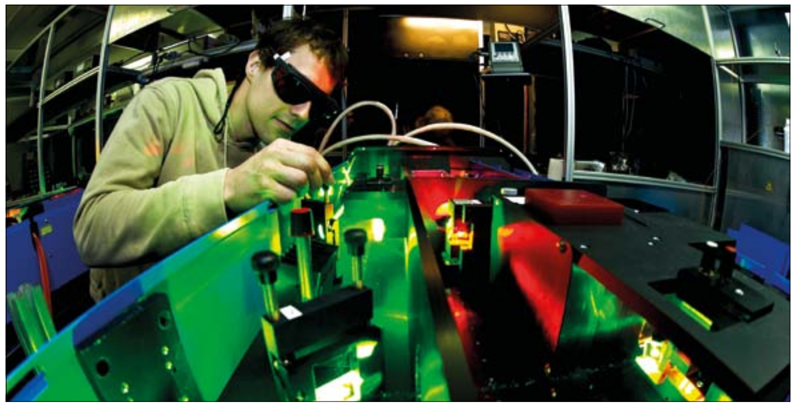
ISOLDE experiments: from a new magic number to the rarest element

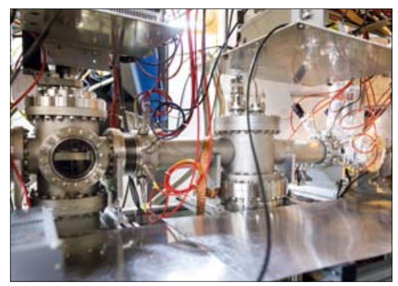
Two teams working on experiments at CERN's ISOLDE facility have published results that extend knowledge in different areas of nuclear and atomic physics. The ISOLTRAP collaboration has measured the masses of exotic calcium nuclei using the new multi-reflection time-of-flight (MR-TOF) instrument, while a team working at the resonant-ionization laser ion source (RILIS) has made the first determination of the ionization potential of the radioactive-element astatine. The results from the two experiments demonstrate well the versatility of the ISOLDE facility.

The ISOLTRAP team used the facility to make exotic isotopes of calcium, with the aim of finding out how their nuclear "shell structure" evolves with increasing numbers of neutrons. By integrating the MR-TOF system into the experiment, the team has made precise determinations of the masses of calcium isotopes up to ^{54}Ca. While the new device has already been applied successfully as a mass separator (*CERN Courier* April 2013 p24), this first use as a mass spectrometer has already led to a key finding and promises further important results in the future.

The results strengthen the prominence in calcium of a "magic number" that was not foreseen in the original nuclear shell model, for which Maria Goeppert-Mayer and Hans Jensen received the Nobel prize in 1963, exactly 50 years ago. In this model, the protons and neutrons in a nucleus form independent "shells" that are similar to those of electrons in atoms. The magic numbers correspond to full nuclear shells, in which the constituents are bound more tightly, leading to greater stability and lighter masses. With 20 protons and 20 neutrons, standard calcium, ^{40}Ca, is doubly magic, while the rare and naturally occurring, long-lived isotope ^{48}Ca has 28 neutrons – another magic number. The measurements by the ISOLTRAP team indicate a new closed-shell structure in ^{52}Ca and therefore a new magic number of 32 (Wienholtz *et al*. 2013). Its shell strength of about 4 MeV rivals that of the classic magic numbers.

These measurements cast light on how nuclei can be described in the context of the fundamental strong force, in particular in terms of predictions using state-of-the-art theory that includes three-body forces, from physicists at the Technical University of Darmstadt. Calcium is the heaviest isotopic chain for which three-nucleon forces – based on an effective field theory of QCD – have been applied. The ISOLTRAP results are in excellent agreement with the theoretical calculations and they show that a description of extremely neutron-rich nuclei can be closely connected to a deeper understanding of nuclear forces.





Above: Lasers are a key component at the ISOLDE facility. Right: The MR-TOF device at ISOLTRAP.

One of the strengths of the ISOLDE facility is the RILIS source, which produces many of the beams. At the source, bunches of protons at 1.4 GeV from CERN's Proton Synchrotron Booster are fired at a thick target of uranium carbide or thorium dioxide. The collisions produce nuclei of many different elements, which diffuse inside a metal cavity held at around 2000°C. Shining overlapping laser beams of chosen wavelengths into this cavity results in the selective ionization of some of the neutral atoms inside. After electrostatic extraction and magnetic mass-separation, the result is a pure beam of one isotope that travels on to a detector.

The latest element to come under scrutiny at RILIS is astatine. With a half-life of just over eight hours for its longest-lived isotope, ^{210}As, astatine is the rarest naturally occurring element and one of the least known. Now, a team at ISOLDE has measured the element's ionization potential for the first time, giving a result of 9.31751 eV (Rothe *et al*. 2013).

The measurement fills a long-standing gap in the Periodic Table because astatine is the last element present in nature for which this fundamental property remained unknown. It is of particular interest because isotopes of astatine are candidates for the creation of radiopharmaceuticals for cancer treatment by targeted alpha-particle therapy. The experimental value for astatine also serves as a benchmark for theories that predict the atomic and chemical properties of super-heavy elements, in particular the recently discovered element 117, which is an astatine homologue.

These two results demonstrate beautifully the wealth of ISOLDE's tool-box for exploring nuclear physics (*CERN Courier* December 2004 p9). They complement well the recent results on the shape of radon nuclei that were observed in post-accelerated beams (*CERN Courier* June 2013 p5).

Further reading

F Wienholtz *et al*. 2013 *Nature* **498** 346.
S Rothe *et al*. 2013 *Nature Communications* **4** doi:10.1038/ncomms2819.

LHC PHYSICS

CMS sees first direct evidence for γγ→WW

In a small fraction of proton collisions at the LHC, the two colliding protons interact only electromagnetically, radiating high-energy photons that subsequently interact or "fuse" to produce a pair of heavy charged particles. Fully exclusive production of such pairs takes place when quasi-real photons are emitted coherently by the protons rather than by their quarks, which survive the interaction. The ability to select such events opens up the exciting possibility of transforming the LHC into a high-energy photon–photon collider and of performing complementary or unique studies of the Standard Model and its possible extensions.

The CMS collaboration has made use of this opportunity by employing a novel method to select "exclusive" events based only on tracking information. The selection is made by requesting that two – and only two – tracks originate from a candidate vertex for the exclusive two-photon production. The power of this method, which was first developed for the pioneering measurement of exclusive production of muon and electron pairs, lies in its effectiveness even in difficult high-luminosity conditions with large event pile-up at the LHC.

The collaboration has recently used this approach to analyse the full data sample collected at $\sqrt{s}$=7 TeV and to obtain the first direct evidence of the γγ→WW process. Fully leptonic W-boson decays have been measured in final states characterized by opposite-sign and opposite-flavour lepton pairs where one W decays into an electron and a neutrino, the other into a muon and a neutrino (both neutrinos leave undetected). The leptons were required to have: transverse momenta p_T>20 GeV/*c* and pseudorapidity |η|<2.1; no extra track associated with their vertex; and for the pair, a total p_T>30 GeV/*c*. After applying all selection criteria, only two events remained – compared with an expectation of 3.2 events: 2.2 from γγ→WW and 1 from background (figure 2).

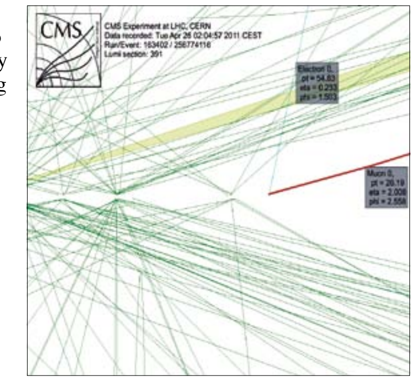


Fig. 1. Above: Proton–proton collisions recorded by CMS at $\sqrt{s}$=7 TeV, featuring candidates for the exclusive two-photon production of a W^+W^- pair, where one W boson has decayed into an electron and a neutrino, the other into a muon and a neutrino.

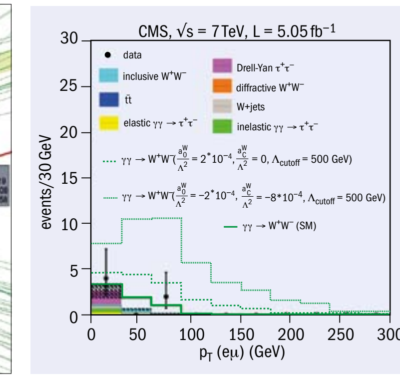


Fig. 2. Top right: The p_T distribution of eμ pairs in events with no extra tracks compared with the Standard Model expectation (thick green line) and predictions for anomalous quartic gauge couplings (dashed green histograms).

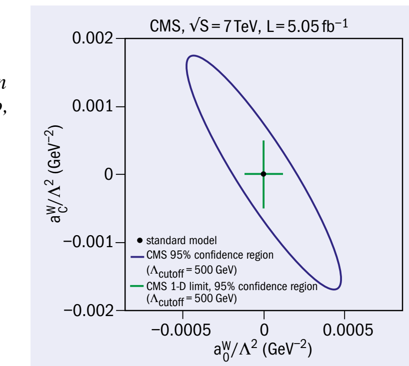


Fig. 3. Right: Limits on anomalous quartic γγWW couplings.

The lack of events observed at large values of transverse momentum for the pair, which would be expected within the Standard Model, allows stringent limits on anomalous quartic γγWW couplings to be derived. These surpass the previous best limits, set at the Large Electron–Positron collider and at the Tevatron, by up to two orders of magnitude (figure 3).

Further reading

CMS collaboration 2013 arXiv:1305.5596 [hep-ex], submitted to *JHEP*.

ALICE through a gamma-ray looking glass

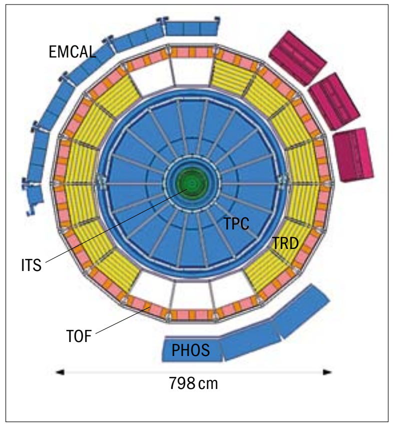
The ALICE experiment is optimized to perform in the environment of heavy-ion collisions at the LHC, which can produce thousands of particles. Its design combines an excellent vertex resolution with a minimal thickness of material. It has excellent performance for particle identification in a large range of momenta as it employs essentially all of the known relevant techniques. Accurate knowledge of the geometry and chemical composition of the detectors is particularly important for tracking charged particles, for the calculation of energy loss and efficiency corrections, as well as for various physics analyses such as those involving the antiproton–proton ratio, direct photons and electrons from semileptonic decays of heavy-flavour hadrons.

The γ-rays produced in proton–proton collisions at the LHC (mainly from π^0 decays), which undergo pair production in the ALICE experiment, provide a precise 3D image of the detector, including the inaccessible innermost parts. The process is almost exactly the same as in 1895 when Wilhelm Röntgen produced an X-ray image of his wife's hand – the inner parts of the body could be seen for the first time without surgery. The main difference lies in the energy of the radiation – of the order of 100 keV for Röntgen's X-rays compared with more than 1.02 MeV for the γ-rays from pair conversions. Importantly for the ALICE experiment, it allows the implementation of the detector geometry in GEANT Monte Carlo simulations to be checked.

To produce the γ-ray image, photons from pair conversions are reconstructed through the tracking of electron–positron pairs using a secondary vertex algorithm. Contamination from other secondary particles, such as K^0_S, Λ and $\bar{\Lambda}$, is reduced by exploiting ALICE's excellent capabilities for particle identification. In this case, the analysis uses the specific energy-loss signal in the time-projection chamber (TPC) as well as the signal in the time-of-flight (TOF) detector. Photons from pair conversions provide an accurate position for the conversion vertex, directional information and a momentum resolution given by that for the charged particles – an advantage over calorimeter measurements at low transverse momentum.

Figure 1 shows the γ-ray picture of the ALICE experiment, i.e. the Y-distribution versus X-distribution of the reconstructed photon conversion vertices, compared with the actual arrangement used in the 2012 run. The different layers of the inner tracking system and the TPC, as well as their individual components (ladders, thermal shields, vessels, rods and drift gas), are clearly visible up to a radius of 180 cm. To obtain a quantitative comparison, the radial distribution of reconstructed photon conversion vertices normalized by the number of charged particles in the acceptance is plotted together with the Monte Carlo distributions in figure 2.

This indicates an excellent knowledge of the material thickness of the ALICE experiment: up to a radius of 180 cm and in the pseudorapidity region $|\eta| < 0.9$, the thickness is 11.4±0.5(sys.)% of a radiation length. The systematic error is obtained from a quantitative comparison of the data with the Monte Carlo distributions, after taking into account the limited knowledge of the true photon sample, of the photon reconstruction efficiency and of the geometry and chemical composition of the detectors.



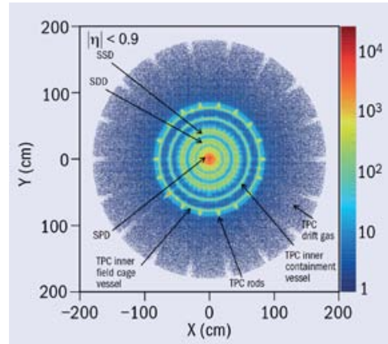


Fig. 1. Top left: Cross-section of the ALICE experiment in the X–Y plane as used in the 2012 run. Top right: Y-distribution versus X-distribution of the reconstructed photon conversion vertices for $|\eta| < 0.9$.

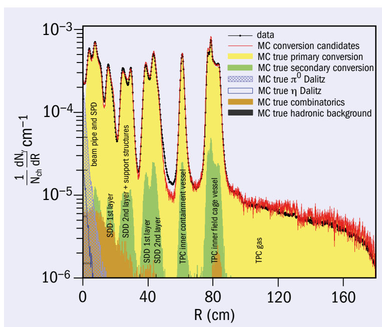


Fig. 2. Radial distribution of reconstructed photon conversion vertices (black) for $|\eta| < 0.9$ compared with Monte Carlo simulations done with Phojet (red). Distributions for true converted photons (yellow), physics contamination from π^0 and η Dalitz decays (blue), random combinatorics (brown) and hadronic background (grey) are also shown.

The accuracy achieved, as well as the full azimuthal acceptance of the central barrel, allows converted photons to be used in physics analyses. So far, photons from pair conversions have been used for the identification of neutral mesons in proton–proton collisions at 7 TeV down to a transverse momentum of 0.3 GeV/*c* – the first time in a collider experiment. Moreover, a direct photon signal observed in lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV has been measured with the photon-conversion method. The latter measurement demonstrates that the quark–gluon plasma formed at the LHC is the hottest matter ever made in the laboratory (*CERN Courier* December 2012 p6).

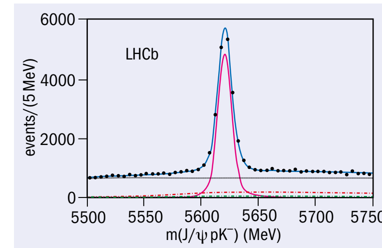
● **Further reading**
B Abelev *et al.* (ALICE collaboration) 2012 *Phys. Lett. B* **717** 162.
M Wilde (ALICE collaboration) 2012 arXiv:1210.5958 [hep-ex].

New precision measurement of the Λ_b lifetime

The value of the Λ_b lifetime has long been controversial but the situation has recently been clarified by a new measurement from the LHCb experiment. There are many ways in which the decays of b quarks are used to search for physics beyond the Standard Model. One strategy, used by the CKMfitter and UTfit teams, is to compare the consistency of various sets of measurements and for this a knowledge of the elements $|V_{cb}|$ and $|V_{ub}|$ of the Cabibbo-Kobayashi-Maskawa (CKM) matrix is essential. One way of determining these from data is to use a theoretical framework called the heavy quark expansion (HQE).

An early prediction from this model was that the Λ_b lifetime was almost equal to that of the B^0 meson but shorter by 1–2%. However, measurements from CERN's Large Electron–Positron collider using the semileptonic decay $\Lambda_b \to \Lambda_c l\nu$ gave values of the ratio of the lifetimes, $\tau(\Lambda_b)/\tau(B^0)$, of around 0.8. This caused concern over the applicability of HQE and various attempts were made to explain the observations. More recent measurements of $\tau(\Lambda_b)$, from the CDF experiment at the Tevatron using $\Lambda_b \to \Lambda_c \pi^-$ (Aaltonen *et al.* 2002) and from ATLAS and CMS at the LHC using $\Lambda_b \to J/\psi\Lambda^0$ (Aad *et al.* 2013, Chatrchyan *et al.* 2013) have indicated larger values but with relatively large uncertainties.

The LHCb collaboration has discovered a new decay mode $\Lambda_b \to J/\psi pK^-$ that is ideally suited for measuring the lifetime, by determining it relative to that for the decays $B^0 \to J/\psi K^{*0}$, $K^{*0} \to K^+\pi^-$. In both the Λ_b and B^0 decays, four charged tracks are produced at the position of the b-hadron's decay. This minimizes systematic uncertainties in the ratio and provides excellent decay-time resolutions of around 40 fs in each mode. The figure shows the signal yield of more than 15,000 Λ_b decays in 1.0 fb^{-1} of LHCb data. Use of ring-imaging Cherenkov detectors in the experiment removes most of the backgrounds from $B_s \to J/\psi K^+ K^-$ and $B^0 \to J/\psi K^+\pi^-$ decays.



Invariant mass of $J/\psi\, p\, K^-$ combinations, showing the clear Λ_b signal.

The collaboration finds $\tau(\Lambda_b)/\tau(B^0) = 0.976\pm0.012\pm0.006$, where the first uncertainty is statistical and the second is systematic (LHCb collaboration 2013). The result demonstrates consistency with the original HQE prediction and should help to resolve issues involving measurements of the CKM parameters $|V_{cb}|$ and $|V_{ub}|$. Using the precisely measured value of $\tau(B^0)=1519\pm7$ fs from the Particle Data Group (Beringer *et al.* 2012) yields a value for $\tau(\Lambda_b)=1482\pm18\pm12$ fs. This result is about twice as precise as the best previous measurement.

Much of the early work on the HQE was done by Nikolai Uraltsev, whose passing earlier this year is much lamented by the community.

● **Further reading**
For more about CKMfitter, see http://ckmfitter.in2p3.fr; for UTfit see www.utfit.org/UTfit/.
G Aad *et al.* ATLAS collaboration 2013 *Phys. Rev.* **D87** 032002.
T Aaltonen CDF collaboration 2002 *Phys. Rev. Lett.* **104** 102002.
J Beringer *et al.* Particle Data Group 2012 *Phys. Rev.* **D86** 010001.
S Chatrchyan *et al.* CMS collaboration 2013 arXiv:1304.7495.
LHCb collaboration 2013 LHCB-PAPER-2013–032, in preparation.

Collaboration

Council updates European Strategy for Particle Physics

On 30 May, at a special meeting hosted by the European Commission in Brussels, the CERN Council formally adopted an update to the European Strategy for Particle Physics. Since the original European strategy was put into place seven years ago (*CERN Courier* September 2006 p29), the LHC has begun routine operation, producing its first major results at centre of mass energies of 7 TeV and 8 TeV, and the global particle-physics landscape has evolved with new neutrino and precision measurements. The updated strategy takes these changes into account and charts a leading role for Europe in a field that is increasingly globalized.

An important issue for the strategy is to ensure that Europe stays at the forefront of particle physics research, which pays dividends in terms of knowledge, innovation, education and training. CERN, in close collaboration with research institutions in its member states and under the guidance of the CERN Council, will co-ordinate future European engagement with global particle-physics projects in other regions.

The strategy emphasizes that Europe and the European particle-physics community should exploit the LHC to its full potential over many years via a series of planned upgrades. Alongside the LHC, the community should also be open to engaging in large particle-physics projects outside Europe and continuing to develop novel techniques for global future accelerator projects. European particle physics should maintain a healthy base in fundamental physics research, with universities and national laboratories contributing to a strong European focus through CERN. Last but not least, the community should continue to invest substantial effort in communication, education and outreach activities to engage global publics with science.

● The updated strategy is reproduced in full in a new brochure *Accelerating science and innovation: societal benefits of European research in Particle Physics*: http://cds.cern.ch/record/1551933. For the original statement, see http://council.web.cern.ch/council/en/EuropeanStrategy/ESParticlePhysics.html.

SESAME

EC and CERN support major facility in Middle East

The European Commission (EC) and CERN have agreed to support the construction of the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) facility, one of the most ambitious research initiatives in the Middle East. SESAME is a unique joint venture based in Jordan that brings together scientists from its members Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey (*CERN Courier* March 2000 p17).

The SESAME synchrotron light source will allow researchers from the region to investigate the properties of advanced materials, biological processes and cultural artefacts. Alongside its scientific goals, the project aims to promote peace in the region through scientific co-operation.

Through an agreement that was announced on 28 May, the EC will contribute €5 million, allowing CERN – working with SESAME – to supply SESAME with magnets for a new electron storage ring at the heart of the facility. This will pave the way for commissioning to begin in 2015. In addition, the EC has already contributed more than €3 million to the project through the European Neighbourhood and Partnership Instrument and by supporting the SESAME networking, computing and data-handling systems.

Magnets of the SESAME booster synchrotron during installation in 2012. Commissioning of the booster will begin in late 2013. (Image credit: SESAME.)

Construction started in 2003. Like CERN, SESAME was established under the auspices of UNESCO. A key impetus to launch was the donation of components from the BESSY laboratory in Berlin. Since then, a growing community of local scientists has been working closely with partner facilities from around the world and several other laboratories have contributed to making the SESAME facility world-class.

ACCELERATORS

ILC Technical Design Report is published

A five-volume report containing the blueprint for the International Linear Collider (ILC) was published on 12 June. The authors of the *Technical Design Report* handed it over to the International Committee for Future Accelerators in three consecutive ceremonies in Tokyo, CERN and Fermilab, representing Asia, Europe and the Americas. Its publication marks the completion of many years of globally co-ordinated R&D and completes the mandate of the Global Design Effort for the ILC.

The ILC – a 31-km electron–positron collider with a total collision energy of 500 GeV – was designed to complement and advance LHC physics. The report contains all of the elements needed to propose the collider to collaborating governments, including the latest, most technologically advanced design and implementation plan optimized for performance, cost and risk.

Some 16,000 superconducting cavities will be needed to drive the particle beams. At the height of operation, bunches of 2×10^{10} electrons and positrons will collide roughly 7000 times a second. The report also includes details of two state-of-the-art detectors to record the collisions and an extensive outline of the geological and civil-engineering studies conducted for siting the ILC.

The design effort continues in the Linear Collider Collaboration (*CERN Courier* April 2013 p5). This combines the two most mature future particle-physics projects at the energy frontier – the ILC and the Compact Linear Collider (CLIC) – in an organizational partnership to co-ordinate and advance global development work for a linear collider. Some 2000 scientists worldwide — particle physicists, accelerator physicists and engineers — are involved in the ILC or in CLIC and often in both projects.

● For the report, see www.linearcollider.org/ILC/Publications/Technical-Design-Report.

*CERN and the Wigner Research Centre for Physics inaugurated the CERN Tier-0 data-centre extension in Budapest on 13 June, marking the completion of the facility (*CERN Courier *June 2012 p9). CERN's director-general, Rolf Heuer, far left, joined József Pálinkás, president of the Hungarian Academy of Sciences, and Viktor Orbán, prime minister of Hungary, in the ceremonial "cutting the ribbon", in the company of Péter József Lévai, far right, general director of the Wigner Research Centre for Physics (RCP). This extension adds up to 2.5 MW capacity to the 3.5 MW load of the data centre at CERN's Meyrin site, which has already reached its limit. The dedicated and redundant 100 Gbit/s circuits connecting the two sites have been functional since February and about 20,000 computing cores, 500 servers and 5.5 PB of storage are already operational at the new facility. (Image credit: Wigner RCP.)*

MUONS

Giant magnet ring makes epic journey

Muon g-2 is a new experiment to measure the anomalous magnetic moment of the muon – in other words, the difference of the value of its magnetic moment g from the simplest expectation of 2. However, before the experiment begins, its centrepiece – a complex electromagnet spanning more than 15 m in diameter – had to embark on a long, careful journey from Brookhaven National Laboratory (BNL) in New York to Fermilab in Illinois.

The magnet ring was built at Brookhaven in the 1990s for the E821 experiment, which ran there from 1997 until 2001. Its measurement of g-2 is still one of the few hints for new physics beyond the Standard Model (*CERN Courier* January/February 2004 p6). Constructed of aluminium and steel with superconducting coils inside, the magnet cannot be taken apart or twisted more than a few millimetres without irreparably damaging the coils. As a result, the Muon g-2 team devised a plan for a five-week journey of 5150 km over land and sea.

The 15-m magnet on the move from Brookhaven. (Image credit: BNL.)

The journey began when the ring left Brookhaven on 22 June. It was loaded onto a specially prepared barge to be taken down the East Coast of the US, around the tip of Florida and up a series of rivers to Illinois. The ring was then attached to a truck built specially for the move and driven to Fermilab to arrive there in late July.

● For more information about Muon g-2, see http://muon-g-2.fnal.gov.

ASTROPARTICLE PHYSICS

DESY inaugurates prototype for the Cherenkov Telescope Array

The first prototype telescope for the planned Cherenkov Telescope Array (CTA) has been inaugurated in Berlin. The prototype was designed and built at DESY in an international collaboration involving more than 1000 scientists and engineers from 27 countries.

The CTA is an international €200-million project to observe cosmic γ rays (*CERN Courier* July/August 2012 p28). Designed to achieve a sensitivity that is 10-times better than existing installations, it will combine three types of telescope, each optimized for its own energy range between a few tens of giga-electron-volts and 300 TeV. The prototype is a full-scale version of the medium-sized telescope (MST) with a tessellated 12-m mirror. Forty MSTs will form the central part of the CTA.

Fully functional mechanically, the prototypes will be used to test many aspects including the drive and safety systems, the understanding of vibrations and deformations, the mirror alignment, telescope pointing and the array control. The results will allow the design of the MSTs to be optimized before their production begins.

The prototype of the medium-sized telescope (MST). In the foreground is a camera housing, now installed on the telescope. (Image credit: DESY.)

Construction of the CTA is expected to commence in 2015 at two sites in the southern and northern hemispheres. The larger southern observatory will include 70–100 telescopes that will be spread over 10 km² and the smaller observatory in the north will have 20–30 telescopes that will be distributed over 1 km². The sites will be chosen at the end of this year.

For further information, see www.cta-observatory.org/ and www.desy.de/cta.

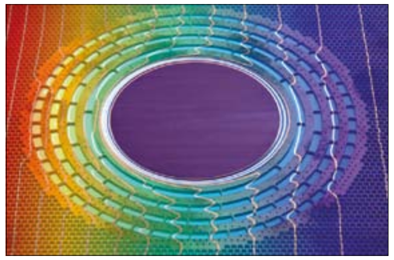
Sciencewatch

Compiled by John Swain, Northeastern University

Researchers construct invisibility cloak for heat

Many kinds of cloaking devices have been proposed – and even built – over the past decade and now there is a new one: a cloak that directs heat flow round an object.

One major approach to cloaking objects from waves uses transformation optics to engineer a material that mimics a curved space around the object to be screened. Robert Schittny of the Karlsruhe Institute for Applied Physics and colleagues have realized that the heat-conduction equation, although it describes diffusion rather than waves, is form-invariant under general curvilinear co-ordinate transformations. This allows a similar trick to be performed. To implement this approach, the team assembled copper rings and bridges interlaid with plastic, creating a heat cloak such that any object placed inside would be undetectable by a heat sensor – heat would instead appear to pass straight through it.



A thermal invisibility cloak. Heat is passed around the central area from the left to the right. Temperature characteristics (white lines) remain parallel. (Image credit: R Schittny/Karlsruhe Inst. of Technology.)

Further reading

R Schittny *et al.* 2013 *Phys. Rev. Letts.* **110** 195901.

Bomb tests cast light on brain regeneration

Just how much new growth of nerve cells occurs in human adults has been difficult to estimate but now Jonas Frisén of the Karolinska Institute and colleagues have come up with an ingenious method that has allowed them to measure how many nerve cells are renewed over the course of adulthood. In other words, the researchers have worked out how to perform carbon-14 dating on brain cells.

Between 1955 and 1963, the testing of nuclear bombs above ground during the Cold War boosted the concentration of carbon-14 in the atmosphere. People who were alive then took up more of it and incorporated it into the DNA of their cells – but this radioactive isotope decays over time.

Using accelerator mass spectroscopy to count carbon-14 atoms in DNA from hippocampal nerve cells from the autopsied brains of 55 people who lived during that time, the team found that about 35% of the nerve cells in the hippocampus had been renewed over the course of adulthood – a result that would seem impossible to obtain any other way.

Further reading

K Spalding *et al.* 2013 *Cell* **153** 1219.

Antisoundproofing

Walls are often erected to block sound but Sam H Lee of Yonsei University and colleagues have instead made one that is good at transmitting sound. As an example, they drilled 10-mm-diameter holes in a 5-mm aluminium sheet – holes that would be too small to allow 1220 Hz sound waves to pass through under normal circumstances. Covering the holes with tensioned plastic film 10 μm thick, they then made air vibrate at 1200 Hz in the holes as if it were massless so that almost 80% of 1220 Hz sound passed through. Moreover, in the holes, the sound intensity rose by a factor of 950. Even higher sound concentrations are possible (they reached a factor of 5700), so apart from making walls that pass sounds of a given frequency this work also opens a way to amplify sound.

Further reading

JJ Park *et al.* 2013 *Phys. Rev. Letts.* **110** 244302.

A tabletop accelerator

Gianluca Sarri of Queen's University of Belfast and colleagues have made a novel accelerator that produces ultrarelativistic positron beams in short pulses (around 30 fs) with small divergences (around 3 mrad) and at high densities (10^{14}–10^{15} cm^{-3}) from a fully optical set-up. The team used the HERCULES laser system at the University of Michigan to blast focused, 30 fs pulses of laser light at a wavelength of 0.8 μm and an energy of 0.8 J onto a supersonic jet of helium doped with 2.5% nitrogen.

The laser set-up could help to model jets of high-speed electrons such as this one emitted by a black hole in galaxy M87. (Image credit: NASA and the Hubble Heritage Team (STScI/AURA).)

The result was a jet – similar to astrophysical leptonic jets – containing electrons, positrons and gamma rays, which could be separated into three distinct beams by a magnetic field. The Lorentz factors for the electrons and positrons produced are between 200 and 300, which is similar to what is observed in astrophysical situations. The system, which apart from the laser is less than 1 m long, is therefore potentially useful not only as a source of particles but also for studying astrophysical jets in the laboratory.

Further reading

G Sarri *et al.* 2013 *Phys. Rev. Letts.* **110** 255002.

Hydrogen and dark energy

New measurements of cosmic hydrogen gas have determined the expansion rate of the universe in a new time window. The Baryon Oscillation Spectroscopic Survey (BOSS) used quasars to "backlight" intergalactic hydrogen and from the spectra measured cosmic expansion at a redshift of about z=2.3, when the universe was about a quarter of its current age of 13.8 billion years.

This fills a gap between values of z of around 1 – where nearby galaxies can be used – and z of around 1110, where radiation remaining from the Big Bang is seen. Apart from confirming cosmic acceleration, this also shows no sign that dark energy has varied over the past 10 billion years.

Further reading

N G Busca *et al.* 2013 *Astronomy and Astrophysics* **552** A96.

A Slosar *et al.* 2013 *JCAP* **4** 026.

Astrowatch

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

Galaxy clusters shed new light on dark matter

What is the actual distribution of dark matter? Does it follow the expectations for cold dark matter (CDM)? "Yes, it does," according to a team of astronomers that has measured the average distribution of dark matter derived from gravitational lensing in 50 clusters of galaxies. The density is observed to decrease outwards from the centre of these cosmic giants in excellent agreement with the predictions of CDM models.

While dark matter still eludes the scrutiny of particle physicists it is becoming more substantial to astrophysicists. Its gravitational role is essential to hold galaxies together in clusters, to account for the high rotational velocity of stars in the outer regions of galaxies and more generally to explain the formation of large-scale structures in the universe. The relatively recent ability to observe the distribution of dark matter in space makes it even more concrete (*CERN Courier* January/February 2007 p11). The method consists of measuring the slight distortion of background galaxies that is induced by the gravitational deformation of space–time along the line of sight. This so-called weak-lensing effect allows astronomers to locate and measure the amount of dark matter, even though it is transparent on the image.

The fluctuations of the cosmic microwave background as observed by the Planck satellite imply that CDM constitutes about 27% of the energy content of the universe (*CERN Courier* May 2013 p12). However, it is important to check whether

The Subaru Telescope on the left and the two domes of the W M Keck Observatory at sunset on Mauna Kea, Hawai'i. (Credit: Mailseth.)

the distribution of mass in galaxy clusters follows the expectations of a medium of dark-matter particles that only interact with each other via gravity and do not emit or absorb photons. An international team led by Nobuhiro Okabe of Academia Sinica, Taiwan, and Graham Smith of Birmingham University used a sample of 50 massive clusters of galaxies to test this. The clusters were selected from an X-ray catalogue in a narrow redshift range of around $z=0.2$ and observed by the Prime Focus Camera of the Japanese 8.2-m Subaru Telescope located next to the two Keck Telescopes on Mauna Kea, Hawai'i. For each cluster, the team derived the weak-lensing signal imprinted in the shape of background galaxies and stacked the results to obtain the average density profile.

The obtained map of the mean dark-matter distribution is remarkably symmetrical with a pronounced central peak. The radial profile is found to be consistent with the Navarro-Frenk-White model at the sub-10% precision level. Measurement of the concentration parameter of the mass in the cluster gives $c_{200}=4.22+0.40-0.36$, which is slightly above but still broadly in line with theoretical predictions for CDM. This result confirms that dark matter behaves in clusters of galaxies as expected by the CDM scenario. It solves a tension between previous observations of individual clusters that found a high central concentration and other studies that included the dynamics of the galaxies in the clusters and suggested a shallower distribution.

In the future, the team would like to improve this analysis by measuring the dark-matter density on even smaller scales right in the centre of these galaxy clusters. This will be possible with the installation of a new camera called the Hyper-Suprime-Cam on the Subaru Telescope, which will also allow astronomers to study smaller galaxy clusters, which are predicted to have a slightly higher dark-matter concentration. The team notes, however, that significant advances on the precision achieved in the current study on massive low-redshift galaxies are only expected with future facilities such as the Large Synoptic Survey Telescope or ESA's Euclid Satellite.

● Further reading

N Okabe *et al.* 2013 *ApJ Lett.* **769** L35.

Picture of the month

This intriguing new view of the stellar nursery IC 2944 has been released to celebrate the 15th anniversary of the Very Large Telescope (VLT). On 25 May 1998, the European Southern Observatory (ESO) released the first-light image obtained by the first of the four Unit Telescopes composing the VLT. One of the first targets of the VLT was a beautiful face-on galaxy called NGC 1232, which revealed the power of the new 8.2-m telescope installed on Cerro Paranal, in Chile, at an altitude of 2635 m. After 15 years, ESO is now releasing a more artistic view of dark clouds of dust, known as the Thackeray globules, silhouetted against the pale pink, glowing gas of the nebula. These globules are under fierce bombardment by UV radiation from nearby young stars and might not be able to collapse to form new stars before being destroyed. (Image credit: ESO.)

CERN Courier Archive: 1970

A look back to CERN Courier vol. 8, July/August 1970, compiled by Peggie Rimmer

News from abroad

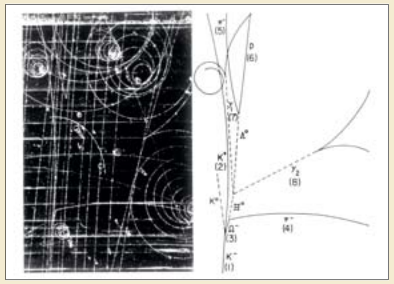
Brookhaven AGS 10th anniversary

The Brookhaven Alternating Gradient Synchrotron AGS really started in 1952. The Cosmotron had accelerated protons beyond 2 BeV (not yet called GeV) and although the machine was still too rickety to do real research, it was clear that the proton synchrotron could be extended to any size. CERN was being established to build on the next larger scale (we did not yet know that the Russians were embarking on the Synchrophasotron) and it seemed straightforward to extrapolate the technique, until one looked critically at the technical and financial problems. Then Courant, Livingston and Snyder hit on alternating-gradient focusing and realized that they had really struck something.

On 29 July 1960, the AGS accelerated proton beams to peak energy [30 GeV] for the first time. Its operation was just pipped by the CERN PS [on 24 November 1959] but, with the experience of the 3 GeV Cosmotron and 6 GeV Bevatron behind them, [the Americans] were the first to get going with an excellent research programme.

High-energy physics began in December 1960 and many of the plums in the newly available energy range – including such sensational discoveries as the existence of two types of neutrino, the identification of the omega minus and the first observation of CP violation – fell to the AGS.

● Compiled from texts on pp210–21, 222–223.



One of the most famous photographs in the history of high-energy physics, taken in the 80-inch bubble chamber at Brookhaven in 1964, in which an Ω^- particle, whose existence was a crucial prediction of unitary symmetry theory, was first found. Negative kaons enter from below and the sequence of interactions from which the Ω^- was identified is shown. (Image credit: BNL.)

Oxford's fast PEPR System

A PEPR [precision encoding and pattern recognition] device, constructed at Oxford University in 1966–67, has measured film of 13,000 events of 740 MeV/*c* negative pion–proton interactions at rates of 150 to 430 events per hour. The upper rate is obtained when measuring two prong events (on average one per 4 frames) for which frame number, topology and vertex guidance have been pre-defined at a conventional scanning table.

PEPR is a CRT line digitizer of the type first constructed by L Pless at MIT. It uses a PDP6 computer and the programs occupy 30 K words of storage, with the general strategy of the successful POLLY system at Argonne, which enables tracks associated with a vertex to be rapidly distinguished.

The main difference from POLLY is that detection and measurement of tracks is done using a 1-mm line image. A fast, track-following program, the only part not written in Fortran IV, maintains the line tangential to the track while predicting along its length. A typical beam track from the 80 cm [Saclay] hydrogen bubble chamber [at CERN] can be measured in about 60 ms. The program outputs "master points" on all tracks associated with a vertex in a given view, and an off-line program MATCHes the images from all three views, discarding redundant tracks. Remaining tracks are input to the geometrical reconstruction program.

The Oxford PEPR system for the automatic measurement of bubble chamber film. (Image credit: Oxford University)

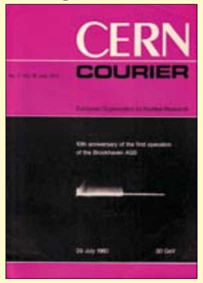
PEPR programs include HELP facilities that show, on a monitor, a scan of any area of film in which some ambiguity has arisen. The operator can then indicate exact vertex position, etc. using a light pen. However, this attempt to rescue doubtful events reduces the measuring rate to 150 events/hour.

In future, a compromise may be adopted in which events whose beam track is not clearly distinguishable in at least two views in the pre-scan are not presented to PEPR. This will reduce operator intervention to around 5% of events and maintain a measuring rate of 200–300 events per hour.

Development work [is planned] to dispense with pre-scan information where film quality is good, and a three-view PEPR is being constructed to allow immediate access to other views of a given track, avoiding the present disadvantages of "post mortem" matching.

● Compiled from texts on pp258–259.

Compiler's Note



The discovery of two neutrino types at Brookhaven's AGS in 1962 and of CP violation in 1963 led to Nobel prizes in physics in 1968 and 1980, respectively. The simultaneous discovery at the AGS and at SLAC of the J/ψ particle in 1974, and therefore the first evidence for the charmed quark, was rewarded with yet another Nobel prize in 1976. Like the Proton Synchrotron at CERN, the AGS continues in service to this day.

With the electronic era of particle-physics detectors fast approaching, pattern recognition of events on bubble-chamber film was reaching its zenith in the late 1960s. Some of those marvellous measuring machines – part mechanical, part electrical and part whatever else was needed (one incorporated a fishing net) – were worthy of Heath Robinson.

The Tevatron's data continue to excite

On 30 September 2011, the Tevatron beams were shut down for the last time. Nevertheless, analysis of data collected during 10 years of proton–antiproton running continues to provide new results, as **Dmitri Denisov** and **Robert Roser** describe.

The first collisions occurred in Fermilab's Tevatron in 1985. Over the following years, both the energy and the luminosity increased (*CERN Courier* November 2011 p28) and by the time operations ceased in 2011 the collision luminosity had reached $7 \times 10^{32}\,cm^{-2}\,s^{-1}$, more than 350 times the original design value. The Tevatron's unique feature was its collisions of protons with antiprotons. While it requires substantial technical efforts to make antimatter – the Tevatron's antiproton source was the world's most powerful producer of antimatter but still incapable by a long way of the destruction imagined in *Angels & Demons* – the study of proton–antiproton collisions provides the opportunity to study quark–antiquark interactions against low backgrounds. By the final shutdown, a total luminosity of $12\,fb^{-1}$ had been delivered to each of the two gigantic Tevatron experiments, CDF and DØ, corresponding to around 5×10^{14} proton–antiproton interactions at a collision energy of 2 TeV.

Images of the two experiments (figure 1) appeared on the front pages of many magazines, in artworks and on TV shows. These modern engineering marvels were largely innovative and demonstrated, for example, the power of a silicon detector in a hadron-collider environment, multi-level triggering, uranium–liquid-argon calorimetry and the ability to identify b quarks. From the collisions provided, the teams recorded the 2×10^{10} most interesting events to tape for detailed examination offline. The analysis effort included searches and studies of new particles, such as the Higgs boson, and precision studies of the parameters of the Standard Model. Many of the exciting results obtained before the end of 2011 have already been summarized in *CERN Courier* (October 2011 p20). This article presents an update on some of the results obtained by CDF and DØ over the past two years.

The search for the Higgs boson was among the central physics goals of the programme for Tevatron Run II (2001–2011) and

Fig. 1. CDF and DØ are complex, general-purpose detectors with over one-million detection channels. Four storeys high, they weigh in excess of 5000 tonnes. (Image credit: Fermilab.)

the challenge of understanding the origin of mass in the Standard Model attracted world-leading experimentalists to Fermilab. In 2005, the data sets provided by the Tevatron reached the point where the search for a substantial number of Higgs events above backgrounds could start. From then until 2012, the analysis teams provided not only increasingly stringent direct mass-exclusions but also reduced indirectly the mass range where the Higgs boson could exist, using highly precise measurements of the masses of the top quark and the W boson (see below). By early 2011, results from the Tevatron and CERN's Large Electron–Positron collider had ▷

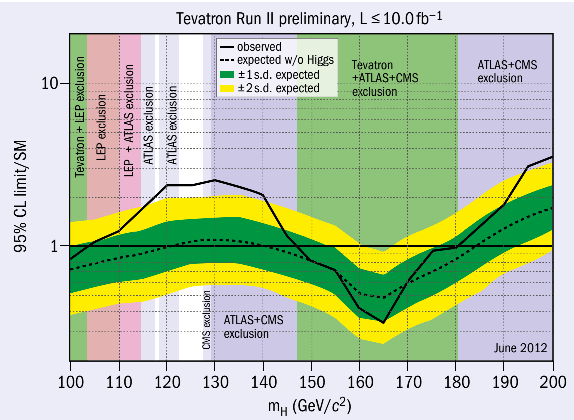


Fig. 2. Higgs-boson searches at the Tevatron. The solid black line indicates the observed limit, which is substantially above the black dashed line and is the expected limit indicating the excess of the "Higgs-like" events in the vicinity of 125 GeV.

reduced the allowed mass range to 125±10 GeV, so the joke among experimentalists at the time was: "We know the mass of the Higgs, we just don't know if it exists."

The CDF and DØ collaborations developed many new experimental methods in their hunt for the Higgs boson, from the combined searches of hundreds of individual channels for the boson's production and decay to an extremely precise understanding of the backgrounds and a high-efficiency reconstruction of the Higgs-decay objects. The Tevatron's high luminosity was the key, because only a few events were expected to remain in the signal region following all of the selections. The unique feature of proton–antiproton collisions was critical for the searches, especially in the decay to a pair of b quarks – the most probable channel for Higgs decay at a mass of 125 GeV. While cross-sections for Higgs production increase with energy and are much higher at the LHC, the increase in the main backgrounds is even faster, so the signal-to-background ratio for this main Higgs-decay channel remains favourable at the Tevatron.

By the early summer of 2012, both CDF and DØ had analysed the full Tevatron data set in all sensitive Higgs-decay modes: bb, WW, ττ, γγ and ZZ. The results included not only larger data sets than before but also substantially improved analysis methods. Multivariate analysis was used to take full advantage of the information available in each event, rather than using the more traditional cuts on kinematical parameters. Such techniques optimize the ratio of signal to background in a multi-dimensional phase space and were critical for reaching sensitivity to the Higgs-boson signal.

At the Tevatron, the primary search sensitive to Higgs masses below around 135 GeV comes from the associated production of the Higgs boson with W or Z bosons, with the Higgs decaying to a pair of b quarks. This topology increases the signal-to-background ratio, because decays to a pair of b quarks have the highest probability while also minimizing backgrounds as the extra W or Z boson provides useful features, both for triggering and for offline event selection. Nevertheless, reconstructing jets from b quarks –

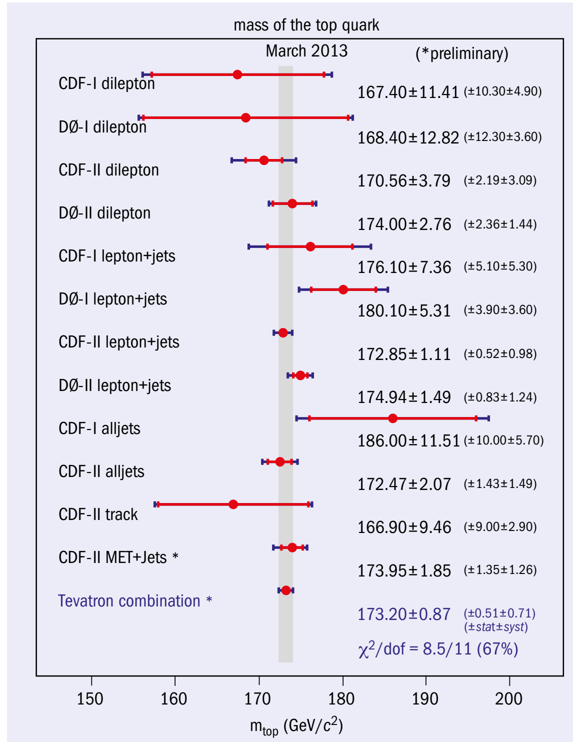


Fig. 3. Tevatron top-quark mass measurements from CDF and DØ. The combination of results from the two experiments reaches a precision better than 1 GeV, or 0.5%.

which sometimes consist of hundreds of particles – with high precision is challenging. This is why the expected shape of the Higgs signal is rather wide, with a mass resolution of around 15 GeV, in comparison with searches in the channels where single particles, such as a pair of photons or leptons, are used to reconstruct the mass of the Higgs.

The CDF and DØ collaborations then combined their search results that summer. The excess observed around a mass of 125 GeV, which the experiments had seen for the previous two years, became even more pronounced (figure 2). The significance of the excess was close to 3σ. What became even more exciting was that in the search channels where the Higgs decays to a pair of b quarks only, the significance of the excess exceeded 3σ, indicating evidence for the production and decay of a Higgs boson at 3.1σ (Aaltonen *et al.* 2012). It was an extremely exciting summer. As the Tevatron passed the baton for Higgs searches (and now studies) to the LHC, its experiments had established evidence of the production and decay of a Higgs boson in the most-probable decay channel to a pair of fermions.

Precise measurements

The Standard Model is one of the most fundamental and accurate theories of nature, so precision measurements of its parameters figure among the major goals and results of the Tevatron's physics

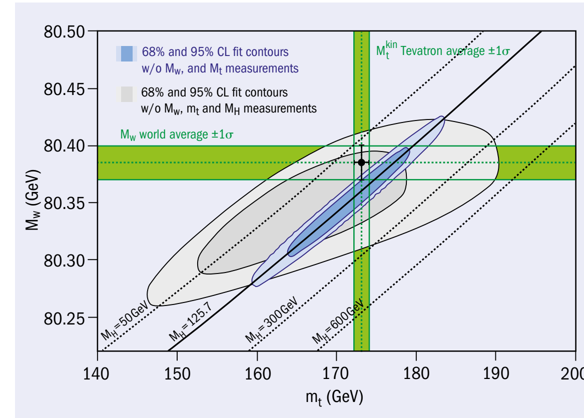


Fig. 4. Measured values of the top-quark mass (Tevatron), W mass (world average, dominated by the Tevatron) and Higgs mass (LHC). All results agree, demonstrating the self-consistency of the Standard Model. (Image credit: Gfitter project.)

programme. Those perfected over the past two years include the determination of the masses of the top quark and the W boson, both of which are fundamental parameters of the Standard Model.

Since the discovery of the top quark at the Tevatron in 1995, measurements of its mass have improved by more than an order of magnitude. In addition to the larger data sets, from some 10 events in 1995 to many thousands in 2012, the analysis methods have also been improved dramatically. One of the innovations developed for precision determination of the top mass – the matrix-element method – is now used in many other studies in particle physics.

In the channel that allows the most accurate mass measurement, the top quark's final decay products are: a lepton (electron or muon); missing energy from the escaping neutrino; a pair of light quark jets from the decay of the W boson; and two b-quark jets. Determination of the energy of the jets is the most challenging task for precision measurement. In addition to using complex methods to determine the jet energy based on energy conservation in di-jet and γ+jet events, the fact that a pair of light jets come from the decay of a W boson with extremely well known mass (see below) is critical in obtaining high precision for the top-quark mass.

Using a large fraction of the Tevatron data, CDF and DØ reached a precision in the measurement of the top-quark mass of less than 1 GeV (figure 3), i.e. a relative accuracy of 0.5% (Tevatron Electroweak Working Group 2013). This is based on the combination of results from both experiments in many different channels. All of the results are in good agreement, demonstrating the validity of the methods that were developed and used to measure the top-quark mass at the Tevatron. Analyses of the full Tevatron data set are in progress and these should improve the accuracy by a further 20–30%. Experiment collaborations at both the LHC (ATLAS and CMS) and the Tevatron have formed a group to combine the results of the top-quark mass measurements from all four experiments. Such a combination will have a precision that is substantially better than individual measurements, because many of the uncertainties are not correlated between the experiments.

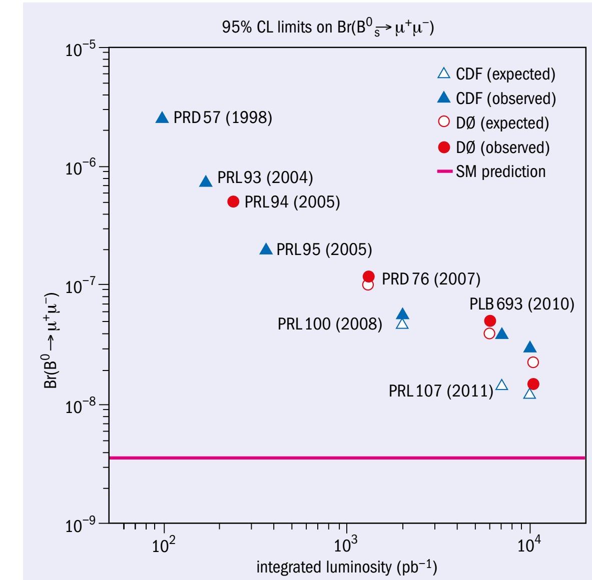


Fig. 5. Steady improvements in the search for rare decay $B_s \to \mu\mu$ at the Tevatron over many years. These results excluded many models of beyond-Standard-Model physics, with the LHCb experiment observing evidence for this rare decay at the Standard-Model predicted level in late 2012.

The measurement of the mass of the W boson requires even higher precision. By the end of the Tevatron's operation, the combined Tevatron measurement for this particle with a mass of 80 GeV reached 31 MeV, or 0.04%. A precise value of the mass of the W boson is critical for understanding the Standard Model; in addition to being closely related to the masses of the Higgs boson and the top quark, it defines the parameters of many important processes. The main decay channel used to measure the W mass is the decay to a lepton (muon or electron) and a neutrino ("missing energy"). The precision calibration of the lepton energy is obtained from resonances with well known masses, such as the J/ψ or the Z boson, while the measurement of missing energy is calibrated using different methods for cross-checks. The calibration of the lepton energy is the most difficult part of the measurement; larger data sets provide more events and improve the accuracy of the measurement.

With up to around 50% of the Tevatron data set, the combined analysis of CDF and DØ gives the mass of the W boson to be 80.387 MeV with an accuracy of 16 MeV – twice as good as only a year previously (Tevatron Electroweak Working Group 2013). The accuracy is now driven by systematic uncertainties. In order to reduce them, careful work and analysis of more data are needed; a precision of around 10 MeV should be reachable using the full data set. Such accuracies were once thought to be impossible to achieve in a "dirty" hadron-collider environment.

In the Standard Model, the masses of the Higgs boson, W boson and top quark are closely related and a cross-check of the relationship is one of the model's most stringent tests. Figure 4 shows recent results for the top-quark mass (from the Tevatron), the W-boson ▷

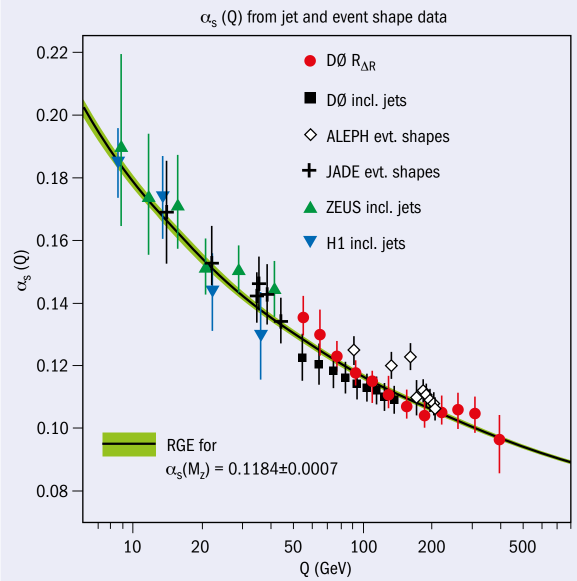


Fig. 6. Running of the strong coupling constant verified at the Tevatron up to Q = 400 GeV or 5 × 10⁻¹⁶ cm.

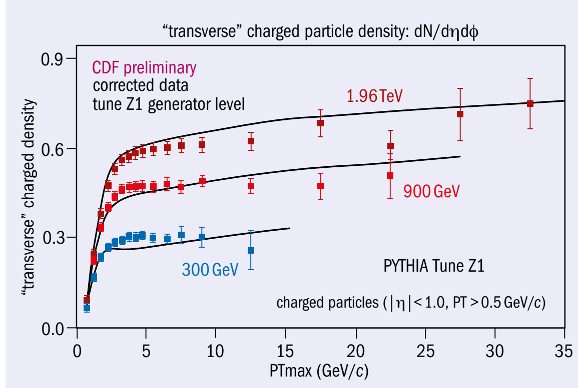


Fig. 7. CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the average density of charged particles in the "transverse" region defined by the leading charged particle as a function of transverse momentum. The points correspond to the average number of charged particles per unit η–φ.

mass (dominated by the Tevatron, with a world-average accuracy of 15 MeV vs 16 MeV Tevatron only) and the mass of the Higgs boson, as measured by the LHC experiments. The good agreement demonstrates the validity of the Standard Model with high precision.

At its inception, researchers had not expected the Tevatron to be the precision b factory that it became. However, with the success of the silicon vertex detectors in identifying the vertexes of the decays of mesons and baryons containing b quarks, the copious production of these b hadrons and the extremely well understood triggers, detectors and advanced analysis techniques, the Tevatron has proved to be extremely productive in this arena. A large number of new mesons and baryons have been discovered there and the properties of particles containing b quarks have been studied with high precision, including the measurement of the oscillation frequency of the B_s mesons.

Studies of particles with b quarks provide an indirect way to look for physics beyond the Standard Model. The rate of the rare decay of the B_s meson to a pair of muons is tiny in the Standard Model but new physics models, including some versions of supersymmetry, predict enhancements. Figure 5 (p19) shows how the steady improvements in the Tevatron limits on the decay rate reached around 10^{-8} by 2012, as more data and more elaborate analysis methods were developed by CDF and DØ.

In late 2011, the ATLAS collaboration presented results indicating the existence of a new particle, which was interpreted as an excited state of a $b\bar{b}$ pair, $\chi_b(3P)$ (*CERN Courier* January/February 2012 p17). It is always important to confirm observations of a new particle with independent measurements and even more important to see such a particle at another accelerator and detector. Within just a couple of months, the DØ collaboration confirmed the observation by ATLAS (Abazov *et al.* 2012). This was the first time that a discovery at the LHC was confirmed using data already collected at the Tevatron.

Many important studies performed at the Tevatron measure properties of the strong force, which holds together protons and neutrons in the nucleus and is described by the theory of QCD. These include extremely accurate studies of the production of jets and of W and Z bosons accompanied by jets. The Tevatron articles that provide information for the development of the QCD run to tens of pages long and have tens of plots and tables documenting – with extremely high precision – the details of interactions between strongly interacting particles.

One unusual property of the strong interaction is that, contrary to electromagnetic and gravity interactions where the force increases when objects come closer to each other, the interaction of quarks becomes stronger as they move apart. The experiments at the Tevatron studied the strength of the strong force vs the distance between quarks, the running of the strong coupling constant, and verified that the strong force steadily decreases down to a distance between particles of around 5×10^{-16} cm (figure 6).

During the last month of the Tevatron run in September 2011, the CDF and DØ experiments collected data at energies below 2 TeV, going all of the way down to 0.3 TeV in the centre of mass. Such data are useful for studies of the energy dependence of the strong interaction and to compare with previous colliders results, such as the Sp$\bar{p}$S proton–antiproton collider at CERN. An interesting recent measurement is the energy dependence of the "underlying event" in the hard scattering of the proton and antiproton – that is, everything except the two outgoing hard-scattered jets from a pair of hard-scattered quarks (figure 7).

There are many instances when the course of physics changed when experimental results did not fit the current theoretical predictions. Quantum theory and relativity were both born from such "clouds" on the clear horizon of classical physics. Several puzzles remain in the Tevatron data, which are leading to analysis and reanalysis of the full data set. These include the observed anomalous dimuon asymmetry, where the production of negative muon pairs exceeds positive pairs, in contradiction with expectations from the Standard Model (Abazov *et al.* 2011). This result has attracted much attention, because it could relate to the observed matter–antimatter asymmetry in the universe.

There is also a puzzling effect in the production of the heaviest known elementary particle, the top quark. When top–antitop pairs are produced, more top quarks follow the direction of the colliding proton than is predicted in the Standard Model (Aaltonen *et al.* 2013, Abazov *et al.* 2013). Some of the models of new physics predict such abnormal behaviour.

Both of these "clouds" have a significance of 2–3σ and both are easier to study in the collisions of protons and antiprotons at the Tevatron. Will these measurements point to new physics or will the discrepancies be resolved with the further development of analysis tools or more elaborate theoretical descriptions based on the Standard Model? In any scenario, exciting physics from the Tevatron data is set to continue.

The Tevatron was at the leading edge of the energy frontier in particle-physics research for more than a quarter of a century. More than 1000 students received their doctorates based on data analysis in the Tevatron's physics programme, which as a result trained generations of particle physicists. So far, in excess of 1000 scientific publications have come out of the programme, helping to shape the understanding of the subnuclear world. Analysis of the Tevatron's unique data set continues and efforts to preserve the data for future access are in progress. There are sure to be many more exciting results in the coming years.

• Further reading

This article has only touched on a few of the recent results from the Tevatron. For all of the results, see the website for CDF at www-cdf.fnal.gov/physics/physics.html and DØ at www-d0.fnal.gov/Run2Physics/WWW/results.htm.

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Résumé

Le Tevatron n'a pas dit son dernier mot

Les faisceaux du Tevatron au Fermilab ont connu un arrêt ultime en 2011. L'analyse des données collectées pendant les dix années d'exploitation proton–antiproton continue toutefois de produire de nouveaux résultats. Depuis, les expériences CFD et DØ ont trouvé des indices de la production et de la désintégration d'un boson de Higgs ayant une masse d'environ 125 GeV. Elles ont également mesuré les masses du quark top et du boson W, et étudié les désintégrations rares des mésons B, avec une précision toujours plus grande. Toutefois, des questions restent en suspens, ce qui promet une physique intéressante en provenance du Tevatron.

Dmitri Denisov and **Robert Roser**, Fermilab.

ClearPEM clarifies breast cancer diagnosis

Knowledge gained in developing particle detectors for the LHC has been used to create a dedicated PET device for breast scans.

Fig. 1. ClearPEM-Sonic installed at Hôpital Nord, in Marseilles. (Image credit: B Frisch 2011.)

Breast cancer is the most frequent type of cancer among women and accounts for up to 23% of all cancer cases in female patients. The chance of a full recovery is high if the cancer is detected while it is still sufficiently small and has not had time to spread to other parts of the body. Routine breast-cancer screening is therefore part of health-care policies in many advanced countries. Conventional imaging techniques, such as X-ray, ultrasound or magnetic resonance imaging (MRI), rely on anatomical differences between healthy and cancerous tissue. For most patients, the information provided by these different modalities is sufficient to establish a clear diagnosis. For some patients, however, the examination will be inconclusive – for example, because their breast tissue is too dense to allow for a clear image – so these people will require further exams. Others may be diagnosed with a suspicious lesion that requires a biopsy for confirmation. Yet, once this biopsy is over, it might turn out to have been a false alarm.

Patients in this latter category can benefit from nuclear medicine. Positron-emission tomography (PET), for example, offers an entirely different approach to medical imaging by focusing on differences in the body's metabolism. PET uses molecules involved in metabolic processes, which are labelled by a positron-emitting radioisotope. The molecule, once injected, is taken up in different proportions by healthy and cancerous cells. The emitted positrons annihilate with electrons in the surrounding atoms and produce a back-to-back pair of γ rays of 511 keV. The γ radiation is detected to reveal the distribution of the isotope in the patient's body. However, whole-body PET suffers from a low spatial resolution of 5–10 mm for most machines, which is too coarse to allow for a precise breast examination. Several research groups are therefore aiming to produce dedicated systems, known as positron-emission mammographs (PEM), that have a resolution better than 2 mm.

One of these groups is the Crystal Clear collaboration (CCC), which is developing a system called ClearPEM. Founded in 1990 as project RD-18 within CERN's Detector Research and Development Committee's programme, the CCC aimed at R&D on fast, radiation-hard scintillating crystals for calorimetry at the LHC (Lecoq 1991). In this context, the collaboration contributed to the successful development of the lead tungstate ($PbWO_4$) crystals now used in the electromagnetic calorimeters in the CMS and ALICE experiments at the LHC (Breskin and Voss 2009).

Building on this experience, the CCC has transferred its knowledge to medical applications – initially through the development of a preclinical scanner for small animals, the ClearPET (Auffray *et al*. 2004 and *CERN Courier* July/August 2005 p27). Indeed, the technical requirements for PET are close to those of applications in high-energy physics. Both require fast scintillators with high light-output and good energy resolution. They need compact and efficient photodetectors that are read by highly integrated, low-noise electronics that can treat the signals from thousands of channels. The CCC also has expertise in co-ordinating an international collaboration to develop leading-edge scientific devices.

Recently, the collaboration has used the experience gained with ClearPET to develop a dedicated PET system for human medicine – the ClearPEM, shown in figure 1 (Lecoq and Varela 2002). The breast was chosen as a target organ because of the benefits related to precise diagnosis of breast cancer. With the ClearPEM, the patient lies in a prone position on a bed designed such that the breast hangs through a hole. A robot moves the bed into position over two parallel detector-plates that rotate around the breast to acquire a full 3D image. In addition, ClearPEM also performs examinations of the armpit – the axilla – by rotating its detector arm by 90 degrees, thereby shifting the plates to be on each side of it. ▷

Research groups are aiming to produce positron-emission mammographs with a spatial resolution better than 2 mm.

Medical physics

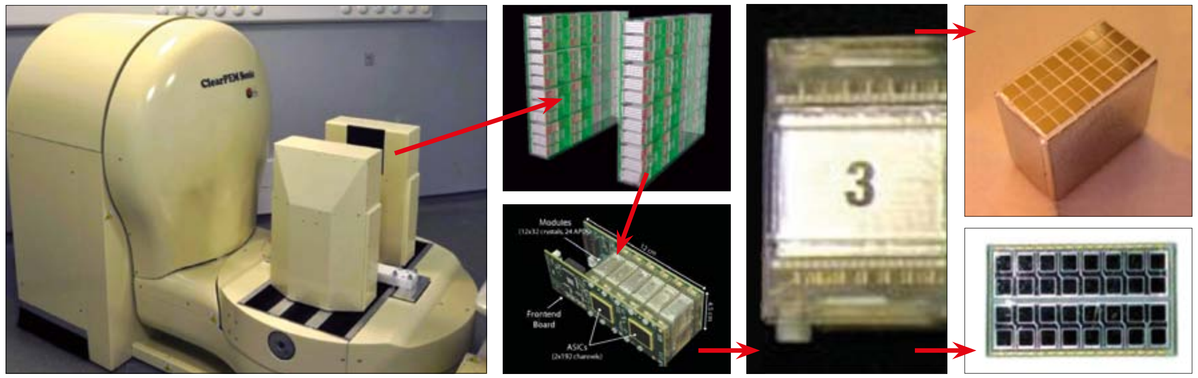

Fig. 2. Each ClearPEM detector plate has modules with crystal matrices, top right, which are read out by APD arrays, bottom right.

Each detector plate contains 96 detector matrices, where one matrix consists of an 8×4 array of cerium-doped lutetium-yttrium silicate (LYSO:Ce) crystals, each 2×2×20 mm^3 in size. As figure 2 shows, each crystal matrix is coupled to two 8×4 arrays of Hamamatsu S8550 avalanche photodiode (APD) arrays, such that every 2×2 mm^2 read-out face is coupled to a dedicated APD. This configuration allows the depth of interaction (DOI) in the crystals to be measured and reduces the parallax error of the lines of response, contributing to better spatial resolution in the reconstructed image. The DOI can be measured with an uncertainty of around 2 mm on the exact position of the γ interaction in the crystal. Each signal channel is coupled to one input of a dedicated 192-channel ASIC, developed by the Portuguese Laboratory for Particle Physics and Instrumentation (LIP). It provides front-end treatment of the signal before handing it over to a 10-bit sampling ADC for digitalization (Varela *et al.* 2007). The image is reconstructed with a dedicated iterative algorithm.

Two ClearPEM prototypes have been built. The first is currently installed at the Instituto de Ciências Nucleares Aplicadas à Saúde in Coimbra, Portugal. The second, installed at Hôpital Nord in Marseilles, France, is used for ClearPEM-Sonic, a project within the European Centre for Research in Medical Imaging (CERIMED) initiative. While ClearPEM provides high-resolution metabolic information, it lacks anatomical details. ClearPEM-Sonic, however, extends the second prototype with an ultrasound elastography device, which images strain in soft tissue (Frisch 2011). The aim is to provide multimodal information that reveals the exact location of potential lesions in the surrounding anatomy. The availability of elastographic information further improves the specificity of the examination by identifying non-cancerous diseases – such as benign inflammatory diseases of the breast – that exhibit higher uptake of the radioactive tracer, fluorodeoxyglucose (^{18}F), or FDG, used in PET imaging.

Both prototypes have been tested extensively. The electronic noise level is under 2%, with an interchannel noise dispersion of below 8%. The front-end trigger accepts signals at a rate of 2.5 MHz, while the overall acquisition rate reaches 0.8 MHz. The detector has been properly calibrated and gives an energy resolution of 14.6% FWHM for 511 keV photons, which allows for efficient rejection of photons that have lost energy during a scattering process. The coincidence-time resolution of 4.6 ns FWHM reduces the number of random coincidences. The global detection efficiency in the centre of the plates has been determined to be 1.5% at a plate distance of 100 mm. The image resolution measured with a dedicated Jasczcak phantom is 1.3 mm.

The competent French authority has approved ClearPEM-Sonic for a first clinical trial on 20 patients. The goal of this trial is to study the feasibility and safety of PEM examinations. In parallel, the results of ClearPEM are being compared with other modalities, such as classical B-mode ultrasound, X-ray mammography, whole-body combined PET and computerized tomography (PET/CT) imaging and MRI, which all patients participating in this trial will have undergone. The ClearPEM image is acquired immediately after the whole-body PET/CT, which avoids the need for a second injection of FDG for the patient. The histological assessment of the biopsy is used as the gold standard.

The sample case study shown in figure 3 is a patient who was diagnosed with multifocal breast cancer during the initial examination. The whole-body PET/CT reveals a first lesion in the left breast and a second close to the axilla. Before deciding on the best therapy, it was crucial to find out whether the cancer had spread to the whole breast or was still confined to two individual lesions. An extended examination with MRI shows small lesions around the first one. The whole-body PET/CT image, however, does not show any small lesions. The standard procedure is to obtain biopsy samples of the suspicious tissue. However, the availability of a high-resolution PET can give the same information. Indeed, when the patient was imaged with ClearPEM, the lesions visible with MRI were confirmed to be metabolically hyperactive, i.e. potentially cancerous. The biopsy subsequently conducted confirmed this indication. This clinical case study, together with several others, hints at how ClearPEM could improve the diagnostic process.

This project successfully demonstrates the value of fundamental research in high-energy physics in applications to wider society. The knowledge gained by an international collaboration in the development of particle detectors for the LHC has been put to use in the construction of a new medical device – a dedicated breast PET scanner, ClearPEM. It provides excellent image resolution that allows the detection of small lesions. Its high detection efficiency allows a reduction in the total examination time and in the amount of radioactive tracer that has to be injected. Last,

Medical physics

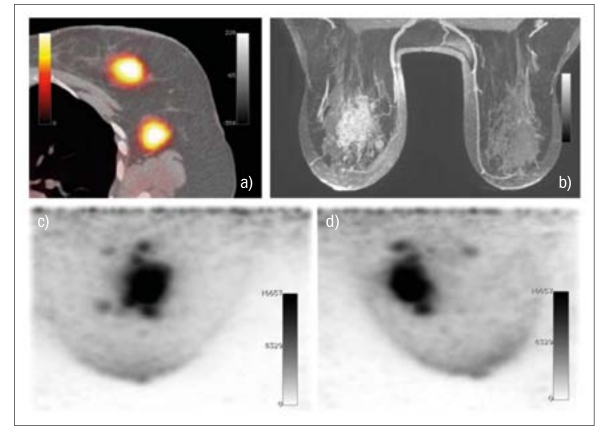

Fig. 3. a) Whole-body PET/CT and b) MRI images of a patient with multifocal breast cancer; c) coronal and d) sagittal ClearPEM views of the same breast.

first clinical results hint at the medical value of this device.

● The members of the ClearPEM-Sonic collaboration are: CERN; the University of Aix-Marseille; the Vrije Universiteit Brussels; the Portuguese Laboratory for Particle Physics and Instrumentation, Lisbon; the Laboratoire de Mecanique et Acoustique, Marseille; the University Milano-Biccoca; PETsys, Lisbon; SuperSonic Imagine, Aix-en-Provence; AssistancePublique – Hôpitaux de Marseille; and the Institut Paoli Calmettes, Marseille.

● Further reading

For more about the CCC, see http://crystalclear.web.cern.ch.

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A Breskin and R Voss (ed.) 2009 *The CERN Large Hadron Collider: Accelerator and Experiments.*
B Frisch 2011 IEEE NSS/MIC *Conf. Rec.* 2011 2267.
P Lecoq *et al.* 1991 CERN/DRDC/91-15.
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Résumé

Le ClearPEM améliore le diagnostic du cancer du sein

Les connaissances acquises lors de la mise au point des détecteurs de particules pour le LHC ont permis de créer un système de tomographie par émission de positons spécialement conçu pour le dépistage du cancer du sein (le ClearPEM). L'appareil a été mis au point par la collaboration Crystal Clear grâce à l'expérience acquise par cette équipe internationale lors du développement de cristaux pour les calorimètres électromagnétiques. Deux prototypes ont été construits et ont fait l'objet de tests intensifs. L'un d'eux, le ClearPEM-Sonic, a été homologué pour un premier essai clinique. Les premiers résultats semblent indiquer une amélioration dans le diagnostic.

Benjamin Frisch, CERN, on behalf of the Crystal Clear collaboration and the ClearPEM-Sonic collaboration.

The case for a circular e^+e^- Higgs factory

Options for a future facility to study Higgs bosons in detail include a larger, more powerful reincarnation of LEP.

The discovery of a Higgs boson by the ATLAS and CMS collaborations at the LHC has opened new perspectives on accelerator-based particle physics. While much else might well be discovered at the LHC as its energy and luminosity are increased, one item on the agenda of future accelerators is surely a Higgs factory capable of studying this new particle in as much detail as possible. Various options for such a facility are under active consideration and circular electron–positron (e^+e^-) colliders are now among them.

In a real sense, a Higgs factory already exists in the form of the LHC, which has already produced millions of Higgs bosons and could produce hundreds of millions more with the high-luminosity upgrade planned for the 2020s. However, the experimental conditions at the LHC restrict the range of Higgs decay modes that can be observed directly and measured accurately. For example, decays of the Higgs boson into charm quarks are unlikely to be measurable at the LHC. On the one hand, decays into gluons can be measured only indirectly via the rate of Higgs production by gluon–gluon collisions and it will be difficult to quantify accurately invisible Higgs decays at the LHC. On the other hand, the large statistics at the LHC will enable accurate measurements of distinctive subdominant Higgs decays such as those into photon pairs or ZZ*. The rare decay of the Higgs into muon pairs will also be accessible. The task for a Higgs factory will be to make measurements that complement or are even more precise than those possible with the LHC.

Attractive options

Cleaner experimental conditions are offered by e^+e^- collisions. Prominent among other contenders for a future Higgs factory are the design studies for a linear e^+e^- collider: the International Linear Collider (ILC) and the Compact Linear Collider (CLIC). In addition to running at the centre-of-mass energy of 240 GeV that is desirable for Higgs production, these also offer prospects for higher-energy collisions, e.g. at the top–antitop threshold of 350 GeV and at 500 GeV or 1000 GeV in the case of the ILC, or even higher energies at CLIC. These would become particularly attractive options if future, higher-energy LHC running reveals additional new physics within their energy reach. High-energy

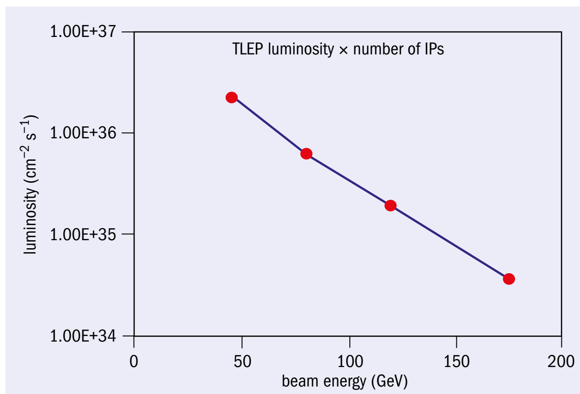

Fig. 1. The luminosity attainable in the TLEP concept as a function of the centre-of-mass energy for four interaction points (IPs).

e^+e^- collisions would also offer prospects for determining the triple-Higgs coupling, something that could be measured at the LHC only if it is operated at the highest possible luminosity.

There has recently been a resurgence of interest in the capabilities of circular e^+e^- colliders being used as Higgs factories following a suggestion by Alain Blondel and Frank Zimmermann in December 2011 (Blondel and Zimmermann 2011). It used to be thought that the Large Electron–Positron (LEP) collider would be the largest and highest-energy circular e^+e^- collider and that linear colliders would be more cost-efficient at higher energies. However, advances in accelerator technology since LEP was designed have challenged this view. In particular, the development of top-up injection at B factories and synchrotron radiation sources, as well as advances in superconducting RF and in beam-focusing techniques at interaction points, raise the possibility of achieving collision rates at each interaction point at a circular Higgs factory that could be more than two orders of magnitude larger than those achieved at LEP. Moreover, it would be possible to operate such a collider with as many as four interaction points simultaneously, as at LEP.

There has been a resurgence of interest in circular e^+e^- colliders being used as Higgs factories.

The concept for a circular e^+e^- collider that has been most studied is TLEP, which would be installed in a tunnel some 80–100 km in circumference. This would be capable of collisions at 350 GeV in the centre of mass, while the specifications call for a luminosity of $10^{34}\,cm^{-2}s^{-1}$ at this energy at each of the four interaction points. With conservative technical assumptions, the corresponding luminosity at a centre-of-mass energy of 240 GeV would exceed $4\times10^{34}\,cm^{-2}s^{-1}$ at each interaction point, as figure 1 (p26) shows (Koratzinos *et al.* 2013). It is encouraging that previous circular e^+e^- colliders – such as LEP and the B factories – have established a track record of exceeding their design luminosities and that there are no obvious showstoppers to achieving these targets at TLEP.

The design luminosity of TLEP would enable millions of Higgs bosons to be produced under clean experimental conditions. The Higgs mass could then be measured with a statistical precision below 10 MeV and the total decay width with an accuracy of better than 1.5%. Many decay modes, such as those into gluon pairs, WW*, ZZ*, and invisible decays could be measured with an accuracy of better than 0.2% and γγ decays to better than 1.5%. This would challenge the predictions of reclusive supersymmetric models, which predict only small deviations of Higgs properties from those expected in the Standard Model, as figure 2 shows.

One essential limitation on the ambition for such a collider is the overall power consumption. The largest, single energy requirement is for the RF acceleration system. Fortunately, because it would operate in continuous rather than pulsed mode, experience with LEP suggests that an overall efficiency above 50% should be attainable. The collision performances quoted here would require an RF power consumption of around 200 MW, to which should be added some 100 MW for cooling, ventilation, other services and the experiments. This is similar to the requirements of other major future accelerators at the energy frontier, such as the ILC and CLIC.

One attractive feature of circular e^+e^- colliders is that they could offer significantly higher luminosities at lower energies. For example, a total luminosity of $2\times10^{36}\,cm^{-2}s^{-1}$ should be possible with TLEP running at the Z peak, and $5\times10^{35}\,cm^{-2}s^{-1}$ at the W^+W^- threshold, which would offer prospects of data samples with the order of 10^{12} Zs and 10^8 W events. The statistical precision and the sensitivity to rare decays provided by such samples extend far beyond those envisaged in previous studies of Z and W physics, corresponding, e.g. perhaps to $\delta\sin^2\theta_W \sim 10^{-6}$ and $\delta m_W \sim 1$ MeV. It will require both a major experimental effort to understand how to control systematic errors and a major theoretical effort to optimize the interpretation of the information obtainable from such data sets.

Although the baseline for TLEP is a tunnel with a circumference of 80–100 km, it is interesting to consider how the performance of a circular e^+e^- collider would scale with its circumference. Generally speaking, a smaller ring would be expected to have a lower maximum centre-of-mass energy, as well as lower luminosities at the energies within its reach. The lower limit of the range of ring sizes under consideration is represented by the LHC tunnel, with its circumference of 27 km. An e^+e^- collider in an LHC-sized tunnel could reach 240 GeV in the centre of mass – for Higgs studies with a luminosity above $10^{34}\,cm^{-2}s^{-1}$ at each interaction point – and could produce impressive quantities of Z bosons and WW pairs. It is difficult to imagine installing an e^+e^- collider in the LHC tunnel

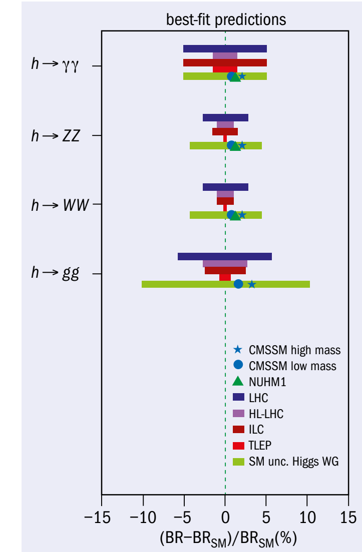

Fig. 2. The accuracies expected for accelerator measurements of various Higgs-decay branching ratios, together with the theoretical predictions at the best fits within some simple supersymmetric model frameworks.

before the LHC experimental programme runs its full course but installation in a new tunnel would not be subject to such a restriction and interest in such a project has been expressed in various regions of the world.

One attractive option would be to envisage a future circular e^+e^- collider as part of a future, very large collider complex. For example, a tunnel with a circumference of 80–100 km could also accommodate a proton–proton collider capable of collisions at 80–100 TeV in the centre of mass, which would also open up the option of very-high-energy electron–proton collisions. This could be an appealing vision for accelerator particle physics at the energy frontier for much of the 21st century. Such a complex would fit naturally into the updated European Strategy for Particle Physics, which has recently been approved.

● Further reading

For more about TLEP, see http://tlep.web.cern.ch.

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Résumé

L'intérêt d'une usine à Higgs circulaire e^+e^-

La découverte d'un boson de Higgs au LHC a ouvert de nouvelles perspectives pour la physique des particules avec accélérateur. L'une d'elles pourrait prendre la forme d'une « usine à Higgs », capable d'étudier la nouvelle particule dans ses moindres détails. Plusieurs options sont à l'étude, notamment celle d'un collisionneur électron-positon circulaire. Dans cet article, John Ellis passe en revue les capacités d'une telle machine, en particulier l'idée d'un TLEP, qui serait installé dans un tunnel de 80 à 100 km de circonférence et pourrait produire des collisions à 350 GeV dans le centre de masse.

John Ellis, King's College London and CERN.

CERN Courier July/August 2013
Interview

From CERN to space – and back

Forty years after his PhD studies at the ISR, former astronaut **Ernst Messerschmid** returned to CERN to talk about his time in space and the imperatives for space flight.

Ernst Messerschmid first arrived at CERN as a summer student in 1970, in the midst of preparations for the start up of the Intersecting Storage Rings (ISR). The studies that he did on beam pick-ups in this ground-breaking particle collider formed the topic of his diploma thesis – but he was soon back at the laboratory as a fellow, sharing in the excitement of seeing injection of the first beams on 29 October that same year. This time he worked on simulations of longitudinal beam instabilities, the subject of his PhD thesis. By the time he came back to CERN some 40 years later to give a colloquium in May this year, he was one of the few people to have worked in space and he had even had a hand in training another former CERN fellow, Christer Fuglesang, before he also flew into space.

A self-confessed "country boy", Messerschmid grew up in Reutlingen in south-western Germany, training first as a plumber and then attending the Technisches Gymnasium in Stuttgart. An aptitude for mathematics turned him towards more academic pursuits and after military service he enrolled at the universities of Tübingen and Bonn. Coming to CERN then as a summer student opened up a new world – an international lab set among the French-speaking communities on the Franco-Swiss border near Geneva. He was on the first steps of the journey that would take him much further afield – into space.

Following his fellowship at the ISR, Messerschmid gained his doctorate from the University of Freiburg. After further experience in accelerators at Brookhaven National Laboratory, he started work at DESY in 1977 optimizing the alternating-gradient magnets for the PETRA electron–positron collider. He looked set for a career in accelerator physics but while deciding on his future he spotted an advert in the newspaper *Die Zeit*: "Astronauts wanted."

Messerschmid had by chance come across ESA's first astronaut selection campaign. "There were five boxes to tick," he recalls. "Scientific training, good health, psychological stability, language skills and experience in an international environment. Being prepared by my time at CERN, I could tick them all." Out of some 7000 applicants, he was among five selected in Germany, of whom three eventually went into space: Ulf Merbold was first, as an ESA astronaut, with Reinhard Furrer and Messerschmid following. "The questions were easy for a 'CERNois' to answer," he says. "The challenge came afterwards."

So, Messerschmid left the world of particle accelerators and in 1978 went to work on satellite-based, search-and-rescue communication systems at the German Aerospace Test and Research Institute (DFVLR), the precursor of the German Aerospace Centre (DLR). He was selected for training as a science astronaut in 1983. Two years later, after scientific training at various universities and industrial laboratories, as well as flight training at ESA and NASA, he was assigned as a payload specialist on the first German Spacelab mission, D1, aboard the *Challenger* space shuttle. With two NASA pilots, three NASA mission specialists and three payload specialists from Europe, this was the largest crew to fly on the space shuttle. Joining Messerschmid from Europe were his fellow German, Reinhard Furrer, and Wubbo Ockels, from the Netherlands. It was the first Spacelab mission in which payload activities were controlled from outside the US. It was also the last flight of the *Challenger* before the disaster in January 1986.

Ernst Messerschmid in the European Spacelab module on which he flew, which is now at EADS, Bremen. In 1985, he was a payload scientist on the D1 mission, where the module – carried by the space shuttle – had a variety of experiments on board. (Image credit: DLR, CC-BY 3.0.)

Working in space

Between 30 October and 6 November 1985, Ernst and his colleagues performed more than 70 experiments. This was the first series to take full advantage of the "weightless" conditions on Spacelab, covering a range of topics in physical, engineering and life-science disciplines. "These were not just 'look and see' experiments," Messerschmid explains. "We studied critical phenomena. With no gravity-driven convection and no sedimentation we could make different alloys – for example, mixing a heavy metal with aluminium. In other experiments we grew uniform, large single crystals of pharmaceuticals for X-ray crystallography studies."

We worked 15–18 hours a day. There was not much time to look out of the window.

It was the experiments – more than the launch and distance from Earth – that proved to be the most stressful. "There were 100 or so professors and some 200 students who were dependent on the data we were collecting," Messerschmid says. "We worked 15–18 hours a day. There was not much time to look out of the window!" But look out of the window he did, and the view of Earth was to leave a lasting impression, not only because of its beauty but also because of the cautionary signs of exploitation. He saw smoke from fires in the rainforests and the bright lights at night over huge urban areas. "Our planet is overcrowded," he observes. "We can't continue like this."

Messerschmid, with white high-neck pullover, next to Bernard Gregory, then director-general, second from left, at the first injection tests into the ISR on 29 October 1970.

After his spaceflight, Messerschmid moved to the University of Stuttgart, where he became director of the Space Systems Institute, doing research and lecturing on space and transportation systems, re-entry vehicles and experiments in weightlessness. He went on to be dean of the faculty of aerospace at Stuttgart and the university's vice-president for science and technology before becoming head of the European Astronaut Centre in Cologne in 2000. There, he was involved in training Fuglesang, who has since flown twice aboard a space shuttle to the International Space Station (*CERN Courier* October 2009 p27). Since 2005, Messerschmid has been back at Stuttgart as chair of astronautics and space stations.

In the meantime, he renewed contact with CERN when he joined Gerald Smith from Pennsylvania State University and others in 1996 on a proposal for a general-purpose, low-energy antiproton facility at the Antiproton Decelerator, based on a Penning trap. Messerschmid and Smith were interested in using antiprotons and in particular the decay chain of the annihilation products for plasma heating in a concept for an antimatter engine. A letter-of-intent described an experiment to measure the energy deposit of proton–antiproton annihilation products in gaseous hydrogen or xenon and compare it with numerical simulations. Messerschmid's student, Felix Huber, worked at CERN for several months but in the end nothing came of the proposal.

Back in Stuttgart, Messerschmid continues to teach astronautics and – as in the colloquium at CERN – to spread the word on the value of spaceflight for knowledge and innovation. "We fly a mission," he says, "and afterwards, as professors, we become 'missionaries' – ambassadors for science and innovation." His "mission statement" for spaceflight has much in common with that of CERN, with three imperatives: to explore – the cultural imperative; to understand – the scientific imperative; and to unify – the political imperative. While the scientific imperative is probably self-evident, the cultural imperative recognizes the human desire to learn and the need to inspire the next generation, and the political imperative touches on the value of global endeavours without national boundaries – all aspects that are close to the hearts of the founders of CERN and their successors.

So what advice would he give a young person, perhaps coming to CERN as a summer student, as he did 40 years ago? The plumber-turned-accelerator physicist who became an astronaut reflects for a few moments. "Thinking more in terms of jobs," he replies, "consider engineering – physicists can also become engineers." Then he adds: "Physicists live on the technologies that engineers produce. Engineers solve the differential equations, they makes theories a reality." Who knows, one day the antimatter plasma-heating for propulsion might become a reality.

• Further reading

To see the colloquium, go to: http://indico.cern.ch/conferenceDisplay.py?confId=252204. To see Messerschmid in space, visit www.youtube.com/watch?v=udWybeP_Awk. For a review of his book, co-authored with Berndt Feuerbacher, *From Space to Earth – Laboratory and Marketplace*, see p54.

Résumé

Du CERN à l'espace, et vice versa

Ernst Messerschmid est venu au CERN comme étudiant d'été, puis comme boursier, où il a travaillé sur les anneaux de stockage à intersections (ISR), mis en service au début des années 1970. Tout semblait le destiner à une carrière dans la physique des accélérateurs, lorsqu'il tomba sur une petite annonce parue dans un journal : « Devenez astronaute ». Grâce, entre autres, à l'expérience qu'il avait acquise au sein de l'environnement international du Laboratoire, il devint l'un des premiers astronautes allemands de l'histoire. Dans cet article, il nous parle de l'époque où il fut astronaute et des obligations d'un vol dans l'espace.

Christine Sutton, CERN.

The return of quarkonia

The physics of heavy quark–antiquark bound states is a long-standing puzzle, made more intriguing by results from the LHC.

Since the revolutionary discovery of the J/ψ meson, quarkonia – bound states of heavy quark–antiquark pairs – have played a crucial role in understanding fundamental interactions. Being the hadronic-physics equivalent of positronium, they allow detailed study of some of the basic properties of quantum chromodynamics (QCD), the theory of strong interactions. Yet, despite the apparent simplicity of these states, the mechanism behind their production remains a mystery, after decades of experimental and theoretical effort (Brambilla *et al*. 2011). In particular, the angular decay-distributions of the quarkonium states produced in hadron collisions – which should provide detailed information on their formation and quantum properties – remain challenging and present a seemingly irreconcilable disagreement between the measurements and the QCD predictions.

Given the success of the Standard Model, why has this intriguing situation not captivated more attention in the high-energy-physics community? The reason may be that this problem belongs to the notoriously obscure and computationally cumbersome "non-perturbative" side of the Standard Model. While the failure to reproduce an experimental observable that is perturbatively calculable in the electroweak or strong sector would be interpreted as a sign of new physics, phenomena requiring a non-perturbative treatment – such as those related to the long-distance regime of the strong force – are less likely to trigger an immediate reaction.

It can also be argued that, until recently, doubts existed regarding the reliability of the experimental data, given some contradictions among results and the incompleteness of the analysis strategies (Faccioli *et al*. 2010). Similar doubts also existed about the usefulness of the data as a test of theory, given their limited extension into the "interesting" region of high transverse-momentum (p_T). The recently published, precise and exhaustive polarization measurements of ϒ from the CDF and CMS experiments (CDF collaboration 2012 and CMS collaboration 2013a), which extend to p_T of around 40 GeV, have significantly changed this picture, building a robust and unambiguous set of results to challenge the theoretical predictions.

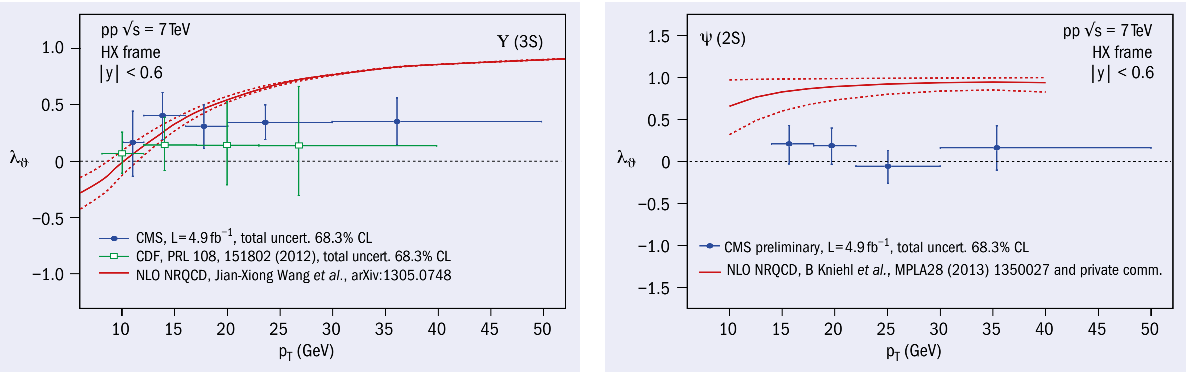
Quarkonium production has been the subject of ambitious theoretical efforts aimed at fully and systematically calculating how an intrinsically non-perturbative system (the $c\bar{c}$ or $b\bar{b}$ state) is produced in high-energy collisions and – potentially – at providing Standard Model references for fully fledged precision studies. The nonrelativistic QCD (NRQCD) framework consistently fuses perturbative and non-perturbative aspects of the quarkonium production process, exploiting the notion that the heavy quark and antiquark move relatively slowly when bound as a quarkonium state (Bodwin *et al*. 1995). This approach introduces into the calculations a mathematical expansion in the quark's velocity-squared, v^2, supplementing the usual expansion in the strong coupling constant α_s of the hard-scattering processes.

The non-perturbative ingredients in these calculations are the long-distance matrix elements (LDME) that describe the transitions from point-like di-quark objects, which can also be coloured ("colour-octet" states), to the colourless observable quarkonia. In principle these could be calculated using non-perturbative models but the current approach leaves them as free parameters of a global fit to some kinematic spectra of quarkonium production. This approach successfully reproduces the differential p_T cross-sections, which has been interpreted as a plausible indication that the underlying assumptions are correct.

The next step in the validation of the NRQCD framework is to make other predictions without changing the previously fitted matrix elements and compare them with independent measurements. The framework clearly predicts that S-wave quarkonia (J/ψ, ψ(2S) and the ϒ(nS) states) directly produced in parton–parton scattering at p_T much higher than their mass are transversely polarized – that is, their angular momentum vectors are aligned as the spin of a real photon. Specifically, considering their decay into $\mu^+\mu^-$, this means that the decay leptons are preferentially emitted in the meson's direction of motion. The measurements made by CDF and CMS contradict this picture dramatically: the ϒ states always decay almost isotropically, meaning that they are produced with no preferred orientation of their angular momentum vectors.

One aspect to keep in mind is that sizeable but not yet well measured fractions of the S-wave quarkonia (orbital angular momentum L=0) are produced from feed-down decays of P-wave states (L=1) leading to more complex polarization patterns. In particular, it is conceivable that the transverse polarization of the directly produced ϒ(1S) mesons, say, is washed away by a suitable level of longitudinal polarization brought by the ϒ(1S) mesons produced in χ_b decays. Such potential "conspiracies" illustrate how intertwined the studies of S- and P-wave states are, showing that a complete understanding of the underlying physics requires a global analysis of the whole family.

Few measurements are so far available on the production and polarization of P-wave quarkonia (χ_c and χ_b), which are experimentally challenging because the main detection channels involve radiative decays producing low-energy photons. In this respect the ϒ(3S) resonance, only affected by feed-down decays from the recently discovered χ_b(3P) state, a presumably small contribution, offers a clearer comparison between predictions and



Polarization parameter λ_θ as a function of p_T for ϒ(3S), left, and ψ(2S), right. The measurements of CDF and CMS are compared with predictions from NRQCD.

measurements: the verdict is that there is striking disagreement, as the left-hand figure above shows.

A more decisive assessment of the seriousness of the theory difficulties is provided by measurements of the polarization of high-p_T charmonia. Such data probe a domain of high values of the ratio of p_T to mass, where the NRQCD prediction is supposed to rest on firmer ground. Furthermore, the heavier charmonium state, ψ(2S), is free from feed-down decays and so its decay angular distribution exclusively reflects the polarization of S-wave quarkonia directly produced in parton–parton scattering, therefore representing a cleaner test of theory. The results for the ψ(2S) shown recently by the CMS collaboration at the Large Hadron Collider Physics Conference, reaching up to p_T of 50 GeV, are in disagreement with the theoretically expected transverse polarization, as the right-hand figure indicates (CMS collaboration 2013b). This challenges the assumed hypothesis that long- and short-distance aspects of the strong force can be separated in calculations on these QCD phenomena. The ultimate "smoking-gun signal" will come from measurements of the polarization of directly produced J/ψ mesons. These probe higher p_T/mass ratios and lower heavy-quark velocities than the studies of ψ(2S) but at additional cost in the necessary experimental discrimination of the J/ψ mesons from χ_c decays.

Definite judgements will have to wait for more thorough scrutiny of the theoretical ingredients. An explicit proof that perturbative and non-perturbative effects can be factorized – already existing for several hard-scattering processes in QCD – has yet to be formally provided for the case of quarkonium production. At the same time, the method to determine the colour-octet transition-matrix elements using measured p_T spectra must be improved. For example, the existing NRQCD global fits use differential cross-sections measured with acceptance corrections that are evaluated assuming unpolarized production, ignoring the large uncertainty that the experiments assign to the lack of prior knowledge about quarkonium polarization (the acceptance determinations strongly depend on the shape of the dilepton decay distributions). Paradoxically, the fit results lead to the prediction of strong transverse polarization. Moreover, while the NRQCD predictions are considered robust only at sufficiently high p_T, the fits assign equal weight to data collected at high p_T and those collected at p_T values that are similar to the quarkonium mass, which drive the results because of their higher precision. Finally, it could be that the higher-order corrections in the perturbative part of the calculations (currently performed at next-to-leading order in α_s) are sizable and not yet well accounted for in current theoretical uncertainties, or that the LDME expansion in the heavy-quark velocity should be reconsidered.

The solution to the quarkonium-polarization problem remains unknown but it seems a safe bet that it will open new perspectives over a whole class of processes. It could unveil an improved Standard Model capable of providing testable predictions for high-momentum production of a large category of non-perturbative hadronic objects. In any case, it will surely stimulate profound rethinking of how such phenomena can be described and predicted.

Further reading

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P Faccioli, C Lourenço, J Seixas and H K Wöhri 2010 *Eur. Phys. J. C* **69** 657.
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CMS collaboration 2013b CMS-PAS-BPH-13–003.

Résumé

Le retour des quarkoniums

Les états liés des paires quark–antiquark lourds (quarkoniums) permettent d'étudier en détail certaines des propriétés fondamentales de la chromodynamique quantique, la théorie des interactions fortes. Toutefois, le mécanisme à l'origine de leur production reste un mystère, malgré des décennies de recherches expérimentales et théoriques. En particulier, on observe une divergence, à première vue inexplicable, entre les mesures et les prédictions de la chromodynamique quantique s'agissant des distributions angulaires des désintégrations des états quarkoniums produits dans les collisions de hadrons. Les résultats du LHC rendent à présent l'énigme encore plus passionnante.

Pietro Faccioli, LIP-Lisbon.

Participants gather in the court of the Complex of San Giovanni in Monte, in the centre of Bologna. (Image credit: Riccardo Serra.)

Beauty in Bologna

The historic centre of Bologna provided an appropriately attractive setting for Beauty 2013, the latest conference on B physics.

Some 100 physicists, including experts from all around the world, converged on Bologna on 8–12 April for the 14th International Conference on B Physics at Hadron Machines (Beauty 2013). Hosted by the Istituto Nazionale di Fisica Nucleare (INFN) and by the local physics department, the meeting took place in the prestigious Giorgio Prodi lecture hall, at the heart of a magnificent complex in the city centre.

The Beauty conference series aims to review results in the field of heavy-flavour physics and address the physics potential of existing and upcoming B-physics experiments. The major goal of this research at the high-precision frontier is to perform stringent tests of the flavour structure of the Standard Model and search for new physics, where strongly suppressed, "rare" decays and the phenomenon of CP violation – i.e. the non-invariance of weak interactions under combined charge-conjugation (C) and parity (P) transformations – play central roles. New particles may manifest themselves in the corresponding observables through their contributions to loop processes and may lead to flavour-changing neutral currents that are forbidden at tree level in the Standard Model. These studies are complementary to research at the high-energy frontier conducted by the general-purpose experiments ATLAS and CMS at the LHC, which aim to produce and detect new particles directly.

During the past decade e^+e^- B factories have been the main pioneers in the field of B physics, complemented by the CDF and DØ experiments at the Tevatron, which made giant leaps in the exploration of decays of the B^0_s meson (p17). Exploiting the highly successful operation of the LHC, the experimental field of quark-flavour physics is being advanced by the purpose-built LHCb experiment, as well as by ATLAS and CMS. In the coming years, a new e^+e^- machine will join the B-physics programme, following the upgrade of the KEKB collider in Japan and the Belle detector there. This field of research will therefore continue to be lively for many years, with the exciting perspective of reaching the ultimate precision in various key measurements.

The experimental field of quark-flavour physics is being advanced by the purpose-built LHCb experiment, as well as by ATLAS and CMS.

The participants at Beauty 2013 were treated to reports on a variety of impressive new results. CP violation has recently been established by LHCb in the B^0_s system with a significance exceeding 5σ by means of the $B^0_s \to K^-\pi^+$ channel (*CERN Courier* June 2013 p7). The ATLAS collaboration reported its first flavour-tagged study of $B^0_s \to J/\psi\phi$ decays and the corresponding result for the $B^0_s - \bar{B}^0_s$ mixing phase ϕ_s, which is in agreement with previous LHCb analyses. LHCb presented the first combination of several measurements of the angle γ of the unitarity triangle from pure tree-level decays. In the field of charm physics, a new LHCb analysis of the difference of the CP asymmetries in the $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$ channels does not support previous measurements that pointed towards a surprisingly large asymmetry (*CERN Courier* April 2013 p7). The CDF collaboration reported on the observation of $D^0 - \bar{D}^0$ mixing, confirming the previous measurement by LHCb. Concerning the exploration of rare decays, LHCb presented the first angular analysis of $B^0_s \to \phi\mu^+\mu^-$.

Di-muons and more

In addition to this selection of highlights, one of the most prominent and rare B decays, the $B^0_s \to \mu^+\mu^-$ channel, was the focus of various discussions and presentations at Beauty 2013. In the Standard Model, this decay originates from quantum-loop effects and is strongly suppressed. Recently, LHCb was able, for the first time, to observe evidence of $B^0_s \to \mu^+\mu^-$ at the 3.5σ level. The reported (time-integrated) branching ratio of $3.2^{+1.5}_{-1.2} \times 10^{-9}$ agrees with the Standard-Model prediction. Although the current experimental error is still large, this measurement places important constraints on physics beyond the Standard Model. It will be interesting to monitor future experimental progress.

With recently proposed new observables complementing the branching ratio, the measurement of $B^0_s \to \mu^+\mu^-$ with increased precision will continue to be vital in the era of the LHC upgrade. ATLAS and CMS can also make significant contributions in the exploration of this decay. Important information will additionally come from stronger experimental constraints on $B^0 \to \mu^+\mu^-$, which has a Standard-Model branching ratio about 30 times smaller than that for $B^0_s \to \mu^+\mu^-$; the current experimental upper bound is about one magnitude above the Standard-Model expectation. Assuming no suppression through new physics, $B^0 \to \mu^+\mu^-$ should be observable at the upgraded LHC.

Altogether, there were 60 invited talks at Beauty 2013 in 12 topical sessions and 11 posters were displayed. In addition to the searches for new physics in the so-called "golden channels", the talks covered many other interesting measurements, as well as progress in theory. Results on heavy-flavour production and spectroscopy at the B factories, the Tevatron and at the ALICE, ATLAS, CMS and LHCb experiments were presented. Despite the primary focus of the conference being on B physics, two sessions were devoted entirely to CP violation in top, charm and kaon physics. There were also presentations on the status of lepton flavour-violation and models of physics beyond the Standard Model, as well as talks on the status and prospects for future B-physics experiments, SuperKEKB/Belle II and the LHCb upgrade. Moreover, each session featured a theoretical review talk. Guy Wilkinson of Oxford University gave the exciting summary talk that concluded the conference.

The charming environment of the old city centre, dating from the Middle Ages, inspired informal physics discussions during tours through beautiful squares and churches. The programme included a visit to the Bologna Museum of History, followed by the conference dinner, with some jazz music to liven up the evening. ▷

Quarks and Beauty: An Encounter at the Airport

Ten years ago, the Beauty 2003 conference took place in Pittsburgh. I had already been working on B physics for some years and I thought this would be an opportunity to learn what was happening in the field and talk to some of the experts. In particular, the programme included a talk by Ed Witten that I was keen to hear. Above all, the conference was being hosted by Carnegie-Mellon University, where I had studied physics in the 1960s. I was looking forward to visiting the campus after decades and meeting my mentor, Lincoln Wolfenstein, who was one of the organizers.

I was based at the University of Aachen but found out that there was a convenient flight from Brussels to Pittsburgh and, as a courtesy, the university proposed that one of its cars could drop me at the airport. On arrival in Brussels, I checked in and proceeded towards immigration. There was a long line of passengers heading to the US, who had to wait for special security clearance. After some time, a young woman representing the airline came to me to ask some questions. I told her I was going to Pittsburgh for a conference. She checked my papers confirming my conference registration and hotel reservation. Then she asked me what the conference was about. To avoid going into detailed explanations, I just said: "It is about elementary particles. About quarks." She looked at me with raised eyebrows that suggested a degree of scepticism, so I decided to explain more about quarks.

"All of the matter you see around you is made of atoms. The centre of the atom is a tiny nucleus. The nucleus itself contains tinier constituents called quarks. There are two main varieties, called up-quark and down-quark. There are some rare varieties, too, which are heavier and unstable. One of them is called the beauty-quark. That is the one the conference is about." I paused to see if she was registering what I said. She had a bemused look, not sure if I was being serious. I thought it was the nomenclature of quarks that confused her. So I said, helpfully: "These names up, down, beauty are sort of arbitrary. There are some people who call the beauty-quark bottom. Not a nice name, in my opinion. I much prefer beauty."

At this stage she was distinctly nervous and went to fetch one of her superiors. This was an older woman with a no-nonsense manner. She asked to see the conference papers that I had in my hand. She glanced at the first page, which was a copy of the conference poster with the name "Beauty 2003" printed in bold letters. She immediately exclaimed: "It's a conference on cosmetics! Why didn't you say so?" Without waiting for my reaction, she picked up my hand-baggage and hustled me past the line of waiting passengers to the top of the queue, where I could proceed to passport control. She wished me a pleasant flight and disappeared.

I did not have the chance to tell her that the beauty-quark is not a cosmetic but rather a laboratory that might shed light on some of the deep mysteries of nature, such as why we exist and why time runs forwards.

● *Lalit M Sehgal, Aachen.*

For Lincoln Wolfenstein, an expert in the phenomenology of weak interactions, who turned 90 in February.

A place of beauty and art, with the backdrop of a 16th-century fresco by Bartolomeo Cesi, the hall was once the dining hall of the nunnery of the Lateran Canons. (Image credit: R Serra.)

The food lived up to the reputation of the traditional Bolognese cuisine and was particularly appreciated.

The 14th Beauty conference marked, for the first time, the dominance of the LHC experiments in the heavy-flavour sector. The field is now entering a high-precision phase for B physics, with the LHC and SuperKEKB promising to enrich it with many new measurements throughout this decade. The forthcoming increase in the beam energy of the LHC will double the b-quark production rate, strengthening its role in the exciting quest for physics beyond the Standard Model.

• Further reading

The detailed programme, including the presenters' slides, is available at the conference website http://beauty2013.bo.infn.it/.

Résumé

La beauté s'invite à Bologne

Des centaines de physiciens se sont réunis à Bologne, du 8 au 12 avril, pour la 14^{e} conférence internationale sur la physique des B avec des machines hadroniques. Pour la première fois, les expériences LHC ont dominé la physique des saveurs lourdes. Les participants ont annoncé de nouveaux résultats impressionnants, non seulement auprès des expériences LHC, mais également des usines à B et du Tevatron. Les exposés ont porté sur les résultats obtenus récemment sur la violation de CP dans le système B_s^0 et les modes de désintégration rares permettant de vérifier le Modèle standard, ainsi que sur un grand nombre d'autres mesures intéressantes et les avancées réalisées sur le plan théorique.

Robert Fleischer, Nikhef and Vrije Universiteit Amsterdam, **Neville Harnew**, University of Oxford, and **Vincenzo Vagnoni**, INFN Bologna.

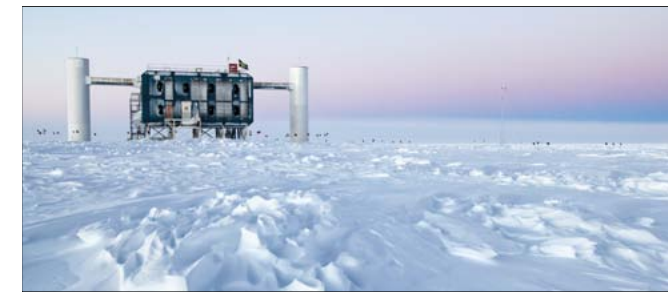
Neutrino telescopes point towards exotic physics

A workshop in Marseilles focused on the search for exotic physics in the era of large-scale neutrino telescopes and the LHC.

It is more than six years since Uppsala University was host to the first Workshop on Exotic Physics with Neutrino Telescopes (*CERN Courier* January/February 2007 p35). Since then, the large neutrino telescopes IceCube and ANTARES have been completed and indirect searches for dark matter, monopoles and other aspects of physics beyond the Standard Model are proceeding at full strength. Indeed, some theoretical models have already been called into question by recent results from these detectors. Meanwhile, searches for dark-matter candidates and indications of physics beyond the Standard Model in experiments at the LHC have set stringent constraints on many models, complementing those derived from the neutrino telescopes. The time was therefore ripe for a second workshop, with the Centre for Particle Physics of Marseilles (CPPM) as host, bringing together 47 experts on 3–6 April.

Dark matter

Review talks on supersymmetric dark-matter candidates and the status of experimental searches opened the first day's sessions. Supersymmetry – still a well motivated candidate for physics beyond the Standard Model – has been put to the first serious tests at the LHC. The discovery there of a Higgs boson at a mass of 126 GeV can be seen either as just another confirmation of the Standard Model or as a first glimpse of physics beyond it. The lack of evidence so far for supersymmetry from direct searches at the LHC raises the limits of supersymmetric particle masses to the scale of tera-electron-volts and has implications for the dark-matter candidates arising in supersymmetric models. The current preferred mass-range for the lightest, stable neutralino is in the region of hundreds of giga-electron-volts. This is good news for neutrino telescopes, which – by design – are sensitive to high-energy particles. The downside is that the predicted rates from annihilation of neutralinos accumulated in heavy celestial objects are low if the constraints from the Wilkinson Microwave Anisotropy Probe and the LHC are taken into account. Only a handful of minimal supersymmetric Standard Model variants predict rates in cubic-kilometre neutrino telescopes that are of the order of 100 events per year or higher.

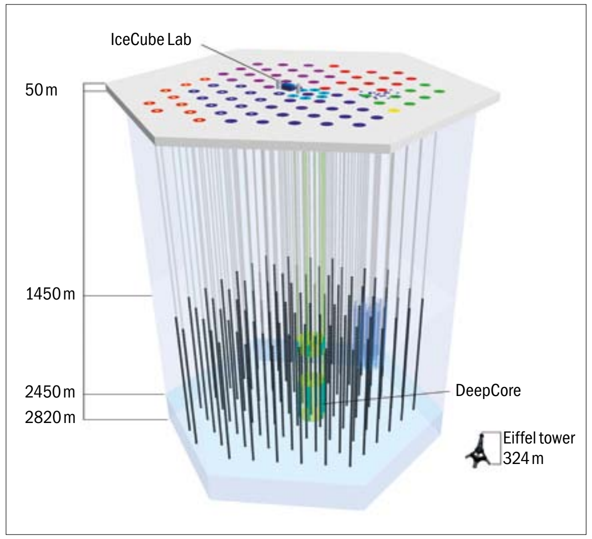


The IceCube lab at the Amundsen-Scott South Pole Station in Antarctica monitors the world's largest neutrino telescope, which consists of more than 5000 optical sensors held in a cubic kilometre of the polar ice cap. (Image credit: NSF/S Lidström.)

However, the neutralino in minimal supersymmetry is not the only viable candidate for dark matter. In models with R-parity violation, a long-lived but unstable gravitino with a mass between a few and a few hundred giga-electron-volts could be a component of the dark matter in the halo of galaxies. Neutrinos of any flavour can be produced in gravitino decay and can be detected by neutrino telescopes. A feature of gravitino dark matter is that it would leave no signal in direct-detection experiments because the cross-section for the interaction between a gravitino and normal matter is suppressed by the Planck mass to the fourth power.

Models with extra dimensions of sizes in the range 10^{-3}–10^{-15} m can also provide dark-matter candidates. Extra dimensions can be accommodated (or even required) in supersymmetry, string-theory or M-theory, where they give rise to branons – weakly interacting and massive fluctuations of the field that represents the 3D brane on which the standard world lives. As stable and weakly interacting objects, branons make a good candidate for dark matter, following the usual scenario: relic branons left over after a freeze-out period during the evolution of the universe accumulate gravitationally in the halos of galaxies, where they annihilate into Standard Model particles that can be detected by gamma-ray telescopes, surface arrays or neutrino telescopes.

From the experimental side, the IceCube, ANTARES, Baikal, Baksan and Super-Kamiokande collaborations presented their latest results on the search for dark matter from different potential sources – the Sun, the Galaxy or nearby galaxies. Their search techniques are similar and based on looking for an excess of neutrinos over the known atmospheric-neutrino background from ▷



DeepCore, the denser array in the centre of IceCube, has opened up the possibility to pursue physics topics otherwise impossible with a detector designed for tera-electron-volt neutrino astrophysics. (Image credit: IceCube collaboration.)

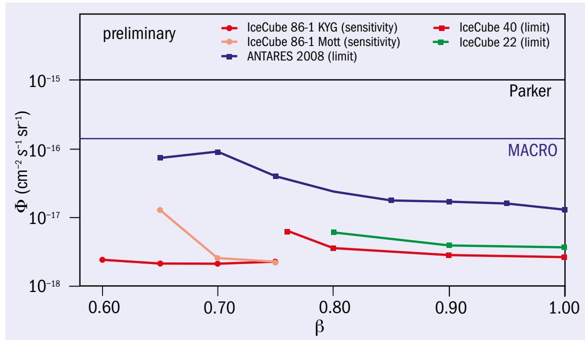
the direction of the sources. DeepCore, the denser array in the centre of IceCube, which was not part of the original design, has proved extremely useful in lowering the energy reach of the detector (*CERN Courier* March 2011 p28). It has opened up the possibility of pursuing physics topics that would otherwise be impossible with a detector designed for tera-electron-volt neutrino astrophysics. Using the surrounding strings of IceCube as a veto, starting and contained tracks can be defined, therefore turning IceCube into a 4π detector with an energy threshold of around 10 GeV, with access to the Galactic centre and the whole Southern Sky.

However, none of the experiments report any excess, and upper limits on the neutrino flux and on the cross-section for interactions between weakly interacting massive particles (WIMPs) and nucleons have been calculated over an ample range of WIMP masses, from about 1 GeV (Super-Kamiokande) to 10 TeV (IceCube). An example of the long-term search capability, as well as consistency in data analysis, was presented for the Baksan experiment. Although it has the smallest of the detectors mentioned above, it has gathered data over 24 years, from 1978 to 2009.

Monopoles, nuclearites and more

Monopoles and heavy, highly ionizing particles leave a unique signal in a neutrino telescope: a strong light-yield along the path of the particle, which is much more intense than the usual track-pattern of a minimum-ionizing muon. If the particle is nonrelativistic, then the separation of such a signal from relativistic muons traversing the detector is even easier. However, dedicated online or offline triggers are needed because for a nonrelativistic particle, light is deposited in the detector over a time of up to tens of milliseconds, instead of a few microseconds for a relativistic muon.

The best limit for fast ($\beta > 0.75$) monopoles, at a level of about



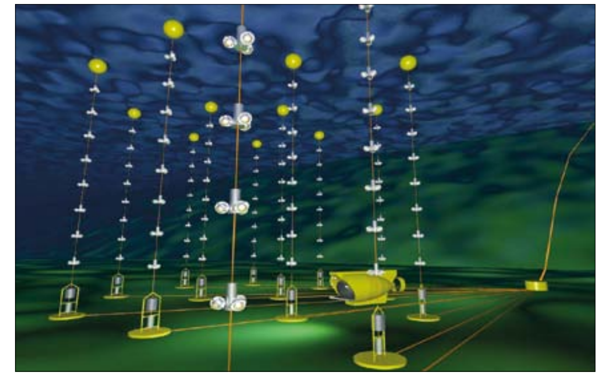
A summary of current flux limits on relativistic ($\beta > 0.6$) monopoles, from the neutrino telescopes ANTARES and IceCube, together with an older limit from the MACRO experiment and the Parker bound. (Image credit: Anna Obertacke, Wuppertal.)

$3 \times 10^{-18}\,cm^{-2}\,s^{-1}$, was presented by the IceCube collaboration using data from its 40-string configuration, although the ANTARES limit – at a level of around $7 \times 10^{-17}\,cm^{-2}\,s^{-1}$ – remains the best so far, at between $0.65 < \beta < 0.75$. However, the sensitivity of the full IceCube detector could extend to $\beta = 0.60$ and reach a level of between $2 \times 10^{-18}\,cm^{-2}\,s^{-1}$ and $10^{-17}\,cm^{-2}\,s^{-1}$ in a one-year exposure, depending on the assumptions on the monopole spin. Results are expected soon, when the ongoing data analysis is finalized.

The Super-Kamiokande collaboration presented a novel way to search for monopoles using the Sun as the target. The idea is that super-heavy monopoles that have been gravitationally trapped in the Sun will induce proton decay along their orbits. Neutrinos with an energy of tens of mega-electron-volts will then be emitted by the decays of the muons and pions produced as the protons decay. This is a low-energy signal that is well below the threshold of large-scale neutrino telescopes but for which Super-Kamiokande has sensitivity. Indeed, this experiment provides the best limit so far on the flux of super-heavy monopoles in the range $10^{-5} < \beta < 10^{-2}$. At the other end of the kinematic spectrum, radio-Cherenkov detectors such as RICE and ANITA provide the best limits for ultrarelativistic monopoles of intermediate mass, at the level of $10^{-19}\,cm^{-2}\,s^{-1}$.

Another bright signature, although from a different process, is produced by slowly moving heavy nuclearites. These massive stable lumps of up, down and strange quarks could be detected in neutrino telescopes through the blackbody radiation emitted by the overheated matter along their path. From the analysis of 310 days of live time in the years 2007–2008, the ANTARES collaboration reported a flux limit at the level of $10^{-17}\,cm^{-2}\,s^{-1}\,sr^{-1}$ for nuclearite masses larger than 10^{14} GeV and β around 10^{-3}. Indeed, the limit improves previous results from the MACRO experiment by a factor of between three and an order of magnitude, depending on the nuclearite mass.

The atmosphere, acting as a target for ultra-high-energy cosmic rays, can be a useful source for searches of physics beyond the Standard Model. The interaction of a cosmic ray of energy around 10^{11} GeV with a nucleon in the atmosphere takes place at a much higher centre-of-mass energy than is achievable in accelerator laboratories and a wealth of physics can be extracted from such collisions. Supersymmetric particles can be produced in pairs



A schematic of the 0.1 km² ANTARES neutrino telescope deployed in the Mediterranean Sea. (Image credit: F Montanet, CNRS/IN2P3 and UJF for Antares/produced with POV-ray.)

and, except for the lightest, they can be charged. Even if unstable, they can, because of the boost in the interaction, reach the depths of a detector and emit Cherenkov light as they traverse an array. The signature is two minimum-ionizing, parallel, coincident tracks separated by more than 100 m. These types of searches are being carried out by the two large neutrino-telescope collaborations, IceCube and ANTARES.

The same interactions of cosmic rays with the atmosphere can also be used to probe non-standard neutrino interactions arising from the effects of tera-electron-volt gravity and/or extra dimensions. At high energies, neutrino interactions with matter may become stronger and the atmosphere can become opaque to neutrinos with energies of peta-electron-volts. A signature in a neutrino telescope would be an absence of regular neutrinos with ultra-high energies accompanied by an excess of muon bundles at horizontal zenith angles. The same effect would take place with a cosmogenic neutrino flux – that is, the flux of neutrinos produced by the interactions of ultra-high-energy cosmic rays with the cosmic microwave background radiation. In the absence of a discovery so far, this flux can be assumed to be at a level compatible with gamma-ray constraints from the Fermi Gamma-ray Space Telescope. The neutrino-nucleon cross-section will depend on the number of extra dimensions, N_D, and a lack of events over the expected flux can be transformed into a limit on N_D. However, the effect in neutrino telescopes with volumes of a cubic kilometre or so is not big. For values of N_D not excluded by the LHC, fewer than one event a year is estimated for IceCube. Only with the larger radio arrays is the expected number of events of the order of 10 per year.

The recent two peta-electron-volt events announced by the IceCube collaboration have already been used to set stringent limits on the violation of Lorentz invariance. If strict Lorentz invariance does not hold, then neutrino bremsstrahlung of electron–positron pairs ($\nu \rightarrow \nu e^+e^-$) is possible, so extragalactic neutrinos would rapidly lose energy via such a process. This would lead to a depletion of the ultra-high-energy neutrino flux at the Earth. Assuming that the IceCube events are, indeed, extragalactic (that is, they have travelled of the order of megaparsecs from the sources to the Earth) and that the extragalactic high-energy neutrino flux is at most at the level of the current IceCube limit of $2 \times 10^{-8}\,cm^{-2}\,s^{-1}\,sr^{-1}$, a limit can be set on Lorentz invariance violation, parameterized by the factor δ, defined as $(dE/dp)^2$-1. Under these assumptions, the bound obtained from the two IceCube events is $\delta < 10^{-18}$, which is orders of magnitude smaller than the current best limit of 10^{-13}.

High-energy atmospheric muons and neutrinos present a background to many of the topics discussed in the workshop. Even if conventionally produced, the absolute normalization of the atmospheric lepton spectrum is not well understood – in particular the contribution from prompt charm decays. Calculations of an atmospheric lepton component, which is rarely considered, from the decays of unflavoured mesons ($\eta, \eta', \rho, \omega, \phi$), were presented at the workshop. These mesons decay rapidly to $\mu^+\mu^-$ pairs and in very-high-energy cosmic-ray interactions the products of the decays can be the dominant muon flux at energies above 10^6 GeV, forming a background that must be taken into account in exotic searches.

One of the unexpected developments in the field since the first ideas of building neutrino telescopes has been their use in neutrino-oscillation physics. On one hand, the detectors can probe oscillation physics at energies not reachable by the smaller detectors. On the other, an aggressive plan to lower the energy threshold of IceCube and the proposed KM3NeT array to the few-giga-electron-volt region is underway, and IceCube has already produced physics results with its low-energy subarray, DeepCore. Plans to build megatonne water-Cherenkov detectors with a giga-electron-volt energy threshold – PINGU at the South Pole and ORCA in the Mediterranean – were also discussed in the workshop. These detectors consist of about 20–50 strings of optical modules with an inter-string separation of 20 m, to be compared, for example, with the 125 m inter-string separation of IceCube or the 70 m inter-string separation of DeepCore. Such detectors may address the issue of the neutrino mass hierarchy at a relatively low cost and on a short timescale because the technology exists already and the deployment techniques are the same as in IceCube and ANTARES.

• Further reading

All of the talks are available on the workshop website at http://indico.in2p3.fr/event/epnt13.

Résumé

Les télescopes à neutrinos à la recherche d'une physique exotique

Le deuxième atelier sur les études de physique exotique au moyen de télescopes à neutrinos s'est déroulé en avril, à Marseille. Six ans après le premier atelier du genre, les sujets de discussion étaient nombreux. La construction des grands télescopes à neutrinos IceCube et ANTARES a en effet été achevée, et les recherches indirectes de matière noire, de monopôles et d'autres phénomènes de la physique au-delà du Modèle standard vont bon train. Les deux télescopes ont déjà permis d'établir de premières limites sur les sections efficaces et les flux, qui complètent les études menées avec des détecteurs de neutrinos plus petits et au LHC.

Carlos de los Heros, Uppsala University, **Vincent Bertin** and **Jürgen Brunner**, CPPM, **Klaus Helbing**, Wuppertal University, and **Vlad Popa**, Institute for Space Sciences, Bucharest.

Faces & Places

APPOINTMENTS

Nigel Lockyer becomes director of Fermilab

Physicist Nigel Lockyer, head of TRIUMF, Canada's national laboratory for particle and nuclear physics, will in September become the sixth director of Fermi National Accelerator Laboratory.

Lockyer will be a familiar face to many. He spent 22 years as a researcher on the CDF experiment at Fermilab, starting in 1984. He was co-spokesperson of the 600-member experiment from 2002 to 2004.

The Board of Directors of the Fermi Research Alliance, which operates Fermilab for the US Department of Energy, offered Lockyer the top job at the conclusion of a nine-month, international search. He will succeed Pier Oddone, who retired in July after eight years as head of the laboratory.

"The opportunity to lead one of the world's most prestigious particle physics laboratories was too good to pass up," says Lockyer. "The future of the field looks to be very exciting; it is a great time to be a particle physicist."

Nigel Lockyer will be Fermilab's next director. (Image credit: TRIUMF.)

Lockyer is an accomplished physicist and leader. In 2006 he won the Panofsky Prize for measuring the lifetime of the bottom quark. During his time as director of TRIUMF, starting in 2007, the laboratory opened new facilities, developed new technology for creating medical isotopes, pushed for the commercialization of innovations from the physical sciences and established Canada's first accelerator-science co-operative agreements with Japan, India, China and Korea.

Brookhaven appoints new physics chair

Laurence Littenberg takes the reins as chair of the physics department at Brookhaven National Laboratory (BNL) as of 1 July. He succeeds Thomas Ludlam, who has served as chair since September 2007.

Littenberg joined BNL in 1974 and has been recognized for his role in ground-breaking research in particle physics. As part of an international team of 50 physicists, Littenberg discovered and measured the rare kaon decay $K^+\rightarrow\pi^+\nu\bar{\nu}$ at the E787 experiment at the laboratory's Alternating Gradient Synchrotron (*CERN Courier* December 2008 p6).

In his new role, Littenberg will oversee BNL's physics portfolio. This includes the Relativistic Heavy Ion Collider, which is the only particle collider currently operating in the US, as well as the laboratory's role at the LHC – particularly in the ATLAS collaboration. He also takes charge of BNL's collaboration in the Baryon Oscillation Spectroscopic Survey and the development of a multi-gigapixel camera sensor for the Large Synoptic Survey Telescope, as well as the long-standing programme in neutrino research, which includes the US proposal for a future Long Baseline Neutrino Experiment (*CERN Courier* April 2012 p12).

Laurence Littenberg is the new chair at Brookhaven's physics department. (Image credit: BNL.)

Rome honours memory of Pontecorvo

The year 2013 is the centenary of the birth of Bruno Pontecorvo, one of the great physicists of the 21st century and a pioneer of high-energy physics. To honour his memory as a person and a scientist, the Physics Department of Sapienza University, in Rome, will hold an international meeting, "The Legacy of Bruno Pontecorvo: the Man and the Scientist", on 11–12 September. Bruno Pontecorvo's life was characterized by his ground-breaking scientific ideas and by his ideological choices, sometimes dramatic, which marked his destiny as a person and as a scientist. The meeting will be a fitting tribute to the memory of the youngest *ragazzo di Via Panisperna* and provide an opportunity to encounter and celebrate his scientific vision and his civil commitment. The scientific programme will revisit the steps that led him to his important scientific results and review his legacy for today's neutrino experiments.

● For further information, see www.roma1.infn.it/pontecorvo/.

AWARDS

Prize time at EPS-HEP 2013

The ATLAS and CMS collaborations are among the winners of the 2013 European Physical Society High Energy Physics prizes. The High-Energy and Particle-Physics Prize, for an outstanding contribution to high-energy physics, is awarded to the two collaborations, "for the discovery of a Higgs boson, as predicted by the Brout-Englert-Higgs mechanism", and to Michel Della Negra, Peter Jenni and Tejinder Virdee, "for their pioneering and outstanding leadership roles in the making of the ATLAS and CMS experiments".

The Young Experimental Physicist Prize for outstanding work by one or more young physicists in the field of particle physics and/or particle astrophysics also recognizes research at the LHC. It goes to Diego Martinez Santos in the Nikhef LHCb group "for his outstanding contributions to the trigger and commissioning of the LHCb experiment, and the analyses leading to first evidence for the rare decay $B^0_s\rightarrow\mu^+\mu^-$".

Zohar Komargodski of the Weizmann Institute receives the 2013 Gribov Medal for outstanding work by a young physicist in theoretical particle physics and/or field theory "for his deep insights into the structure of the renormalization group in four-dimensional field theories and, in particular, his proof (with Adam Schwimmer) of the a-theorem".

Left to right: EPS-HEP prize-winners Tejinder "Jim" Virdee and Michel Della Negra of CMS and Peter Jenni of ATLAS.

In the field of neutrino physics, the Giuseppe and Vanna Cocconi Prize for an outstanding contribution to particle astrophysics and cosmology in the past 15 years goes this year to Arthur McDonald, director of the Sudbury Neutrino Observatory (SNO) collaboration and Yoichiro Suzuki, director of the Kamioka Observatory, "for their outstanding contributions to the solution of the solar neutrino puzzle by measuring the flux of all neutrino flavours from the Sun with the Super-Kamiokande and SNO experiments".

Finally, Don Lincoln of Fermilab (and the University of Notre Dame) is the first non-European to receive the Outreach Prize, for outstanding outreach achievement connected with high-energy physics and/or particle astrophysics, "for communicating in multiple media the excitement of high-energy physics to high-school students and teachers and the public at large".

● The awards are to be presented at the EPS-HEP 2013 in Stockholm on 18–24 July.

In a ceremony on 29 May, Roy Kerr of Canterbury University in Christchurch, New Zealand, received the Albert Einstein Medal 2013, awarded by the Albert Einstein Society, in Bern. The medal, which is to honour extraordinary achievements related to Einstein's legacy, is awarded to Kerr for his "1963 discovery of a solution to Einstein's gravitational field equations". The Kerr metric describes space–time around a spherical mass with angular momentum, such as a rotating black hole.

The Albert Einstein Society was founded in Bern in 1977 and the first medal was awarded to Stephen Hawking in 1979, the centenary of Einstein's birth. The society also maintains Einstein's former flat at 49 Kramgasse in Bern as a commemoration site open to the public.

Roy Kerr with the 2013 Albert Einstein Medal. (Image credit: Edith Ruchti, Bruegg.)

Steve Myers, director of accelerators and technology at CERN, is to become an officer of the Order of the British Empire (OBE) for services to science and technology, as announced in the Queen's Birthday Honours list for 2013. Myers has had a leading role in the development of CERN's particle colliders over the past 40 years, including the Intersecting Storage Rings, the Large Electron–Positron collider and the LHC. In his current role at CERN, he is responsible for the exploitation of the LHC.

Additional honours this year include an OBE for James Hough, chief executive of Scottish Universities Physics Alliance and research professor in natural philosophy at the University of Glasgow, for services to science. Hough is well known for his research on gravitational waves and is the UK's principal investigator on the GEO 600 Gravitational Wave Detector being built by a University of Hanover/MPQ/University of Glasgow consortium.

Steve Myers, OBE.

2013 Markov prize recognizes progress in neutrino oscillations

Contributions to the study of neutrino oscillations in experiments with accelerator and reactor neutrinos, and to the measurement of the mixing angle θ_{13}, link the winners of the 2013 Markov Prize. Yury Kudenko of the Institute for Nuclear Research (INR) of the Russian Academy of Sciences (RAS), Moscow, and Alexander Olshevsky, head of the Nuclear Problems Laboratory of JINR, Dubna, received the award at the 2013 Markov Readings held at the INR on 14 May.

Under Kudenko's leadership, the Russian group working on the long-baseline experiment T2K in Japan developed a unique scintillation detector for the near detector. The group continues to participate in data taking and analysis. Olshevsky is a leader of the JINR teams working on the OPERA and the Daya Bay neutrino-oscillation experiments. He and his group made significant contributions to the precision measurement of θ_{13} at Daya Bay.

Left to right: INR deputy director, Leonid Bezrukov, Alexander Olshevsky, Yury Kudenko and academician Victor Matveev. (Image credit: INR.)

The Markov Prize was established by INR-RAS in commemoration of Moisey Markov (1908–1994), one of the founders of the institute. The prize is awarded each year at the Markov Readings, an international seminar held to commemorate the Russian physicist, who made pioneering contributions to neutrino physics, as well as to quantum gravity and at the borderline between particle physics and cosmology.

CERN, Higgs and Englert receive Prince of Asturias award

In an announcement made on 29 May, the Prince of Asturias Foundation awarded François Englert, Peter Higgs and CERN the 2013 Prince of Asturias Award for Technical and Scientific Research. The awards will be presented in the autumn in Oviedo at a ceremony chaired by the Prince of Asturias, Felipe de Borbón, heir to the throne of Spain and honorary president of the foundation.

Award winners François Englert, left, and Peter Higgs at CERN on 4 July 2012.

The awards date back to 1981 and seek to encourage and promote scientific and cultural values.

The award recognizes that science is performed through collaboration of theory and experiment and through the efforts of the thousands of particle physicists involved in CERN's research. Both Englert and Higgs paid tribute to Robert Brout, who passed away in May 2011 and whose work contributed to the Brout-Englert-Higgs mechanism.

Honours

The Royal Society elects new fellows

Two particle physicists have joined the ranks of Fellows of the Royal Society (FRS) in the UK following the 2013 election in May.

Nigel Glover of the University of Durham has made pivotal research contributions to the understanding of data collected at high-energy particle colliders. His theoretical studies of weak boson, Higgs and jet production in particular are used worldwide. He is especially distinguished for his contributions to the development and exploitation of the perturbative structure of QCD.

Nigel Glover, left and Terry Wyatt, now both FRS. (Image credits: G Robson and T Wyatt.)

Terry Wyatt of the University of Manchester is distinguished for his contributions to the experimental verification of the Standard Model. In particular, he has developed powerful discriminants of signatures for the production of heavy quarks (b and t) and electroweak bosons (W and Z) implemented at CERN's $Sp\bar{p}S$ and Large Electron–Positron colliders and at Fermilab's Tevatron.

Workshop

CAS course in Italy specializes in superconductivity

This year's spring CERN Accelerator School (CAS) focused on superconductivity for accelerators. Held at the Ettore Majorana Foundation and Centre for Scientific Culture (EMFCSC) in Erice on 24 April – 4 May, it attracted 94 participants representing 23 nationalities, including an Ethiopian studying in Germany.

Following some lectures to recapitulate background accelerator physics and the fundamental processes of superconductivity, the course covered a range of topics in superconductivity and highlighted the latest developments in the field. Realistic case studies and topical seminars completed the programme, which featured 35 lectures, three seminars and seven hours of case studies. The participants pursued the case studies with great enthusiasm and produced some excellent results.

Participants at the spring CAS travelled to Italy from far and wide, including Belarus, China, India, Japan and North America. (Image credit: Alessandro Noto EMFCSC.)

The general feedback was positive and reflected the high standard of the lectures. In addition to the academic programme, the participants had the opportunity to visit the Museum of the Nave Punica in Marsala and the Greek temple and Hellenistic theatre at Segesta.

● The next CAS will be an advanced-level course held in Trondheim, Norway, on 18–29 August (http://cas.web.cern.ch/cas/).

Harald Fritzsch, right, of the Ludwig-Maximilians-Universitäet in Munich visited the University of Leipzig on 16 May to receive an honorary degree for his work on quantum chromodynamics. Growing up in East Germany, Fritzsch had studied at Leipzig in the years 1963–1968. Beate Schuecking, left, of the faculty of medicine, is the president of Leipzig University. (Image credit: Leipzig University.)

Workshop

Taming the beam–beam effect

An ICFA mini-workshop on "Beam–Beam Effects in Hadron Colliders" took place at CERN in March to discuss and summarize the current understanding of beam–beam effects. Organized by the LHC beam–beam team and sponsored by the International Committee for Future Accelerators (ICFA), the Ecole Polytechnique Fédérale de Lausanne and the High-Luminosity LHC project, it attracted around 60 accelerator physicists from laboratories worldwide.

A challenge with most particle colliders is the demand to extend the physics capabilities by increasing the luminosity, that is the collision rate. However, the "beam–beam interaction" has been and continues to be a performance-limiting effect for both hadron and lepton colliders. This occurs in colliders when the beams experience each other's electromagnetic fields as they pass through common beam pipes in the region of the experiments. Complex collision patterns can lead to unwanted and sometimes unexpected effects and problems including instabilities, particle losses, orbit distortions and increases in beam size. An unexpected additional problem occurs in the LHC where the instantaneous luminosity might be too large to be exploited efficiently by the experiments. The understanding, control and optimization of these effects will be essential for extending the physics reach of today's colliders.

The workshop at CERN capitalized on what has already been learnt at existing colliders. Experimental data from the LHC, Fermilab's Tevatron and the Relativistic Heavy-Ion Collider at Brookhaven cast light on beam–beam effects in hadron colliders. Several years of LHC operation have provided valuable data and experience and led to much better understanding as well as some unexpected results. Data were also presented from lepton colliders such as KEKB, VEPP, BEPC and DAPHNE, where novel schemes including the use of crab cavities to minimize the side-effects of crossing angles have been tested. These concepts are highly relevant for the High Luminosity LHC upgrade programme and for future collider studies.

Advances in the theoretical treatment of beam–beam effects and in simulation techniques were discussed in dedicated sessions. New tools now enable beam–beam effects to be predicted more reliably, allowing improvements to be made in the design of future colliders and upgrade projects.

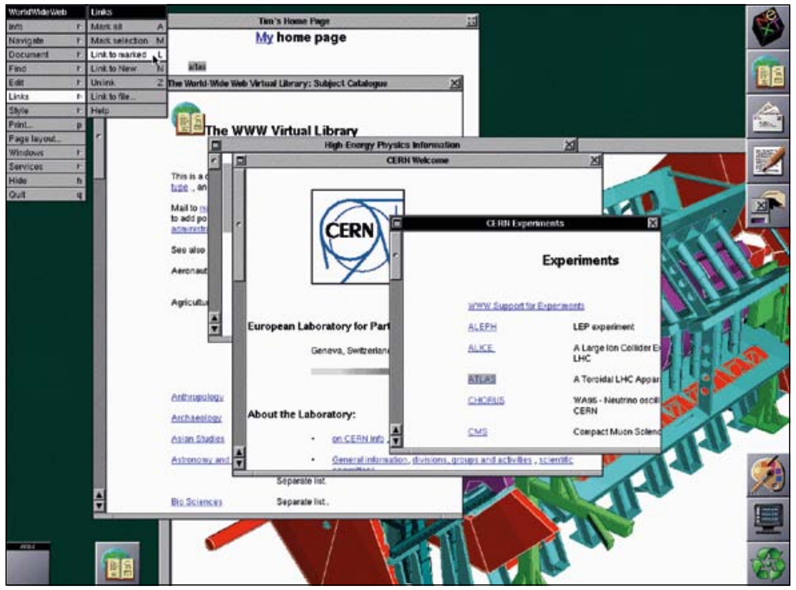
The impact of beam–beam effects on the operation of the LHC was discussed in other sessions, with presentations on the requirements of the LHC experiments and for the operation of the collider. The need for luminosity-levelling techniques to make optimal use of the luminosity is a new aspect of beam–beam studies. The possible implementation of such techniques and their expected side effects through the beam–beam interaction need attention and careful design. Sufficient diagnostic tools form an important ingredient in this context. An important part of the work at the meeting was dedicated to discussing possible beam–beam compensation schemes and their application to the LHC.

The outcomes of the topical sessions were put together in a summary session chaired by Alex Chao of Stanford University and SLAC. Giving his personal impressions, he emphasized the remarkable progress and large number of new ideas and concepts that have been developed in recent years. New effects, such as the interplay between beam–beam interactions and other components – for example electron cloud and machine impedance – need to be studied in more detail. Although the work might not be easy, the approach to this interesting field of accelerator physics is promising.

● For further details, see https://indico.cern.ch/conferenceDisplay.py?confId=189544.

COMPUTING

CERN launches project to restore info.cern.ch



A screenshot of the original NeXT web browser as it looked in 1993.

On 30 April 1993, CERN published a statement making World Wide Web technology available on a royalty-free basis. This allowed the Web to flourish by making the software required to run a web server, a basic browser and a library of code, all freely available. To mark the 20th anniversary of this publication, CERN has started a project to restore the first website and preserve digital assets associated with the birth of the Web.

The plan is to re-establish the first web address – http://info.cern.ch – putting back the files that were there in their earliest possible iterations, enabling people to experience the line-mode browser and the NeXT browser and editor. The team will look at the first Web servers at CERN and see what assets from them can be preserved and shared, restoring machine names and IP addresses to their original state. Through this restoration and more, the project aims to tell the story of the early days of webs.

● To learn more about the first website project or to get involved, visit http://first-website.web.cern.ch.

BRUNOFEST

Berkeley honours Zumino


Bruno during a trip to Europe in 2011. (Image credit: Courtesy Sergio Ferrara.)

Friends, collaborators and colleagues of Bruno Zumino met at the Berkeley Center for Theoretical Physics at the beginning of May to honour him on the occasion of his 90th birthday. A leader in theoretical physics for many decades, Bruno is universally respected as a kind and generous colleague and adviser to many generations of younger physicists. The event was a multifaceted celebration with many personal reminiscences adding flavour to the scientific memories and latest news.

Featuring among Bruno's many achievements that were recalled at the conference – in particular by Edward Witten – were his rigorous proofs with Gerhart Lüders of the spin-statistics and CPT theorems, among the most profound results in quantum field theory. Several speakers, including Steven Weinberg, also mentioned his beautiful formulation – together with Curtis Callan, Sidney Coleman and Julius Wess – of effective Lagrangians for spontaneously broken symmetries. Participants were reminded that Bruno and Wess introduced ideas from geometry and topology into particle physics that underlie the modern treatment of anomalies and much else.

Currently, much theoretical and experimental interest centres on supersymmetry, a concept introduced into realistic 4D field theories in a brilliant series of papers that Bruno wrote in collaborations with Julius Wess, Sergio Ferrara and John Iliopoulos at CERN in 1973 and 1974. Ferrara and many others talked about some of the tremendous theoretical ramifications of this pioneering work, which also underlies hopes for new physics beyond the Standard Model, as reviewed by Luciano Maiani, Fabiola Gianotti, Gigi Rolandi and John Schwarz, in particular. One highlight of the meeting was Gianotti's public lecture, which provided a welcome opportunity to share some of the latest news from CERN on the Higgs boson discovery with the Berkeley community and to remind them of the intellectual giant living in their midst.

Bruno's more recent influential developments were also the focus of discussion at the meeting, notably his pioneering work with Mary Gaillard on duality. The concept of duality underlies many of the most exciting developments in string theory throughout the past couple of decades.

Bruno has been a pillar of the Berkeley physics community since moving from CERN in 1981 and many of his present and former colleagues and students there expressed the scientific esteem and personal respect they have for him. All of the participants wish Bruno the best for the future. Will nature be kind enough to reveal supersymmetry soon?

OUTREACH

CERN hosts its first TEDx


TEDxCERN hosts included Nobel laureate George Smoot.

The inaugural TEDxCERN event took place on 3 May in the Globe of Science and Innovation, with a live webcast elsewhere at CERN and participating institutes around the world and online. Using the theme of "multiplying dimensions", the event went beyond particle physics with speakers ranging from pioneers to young scientists.

A packed audience was enthralled by talks on topics ranging from networking chemistry and DNA to citizen astronomy, the early universe and the Higgs boson, and from seafloor earthquakes and "big data" to consciousness, gendered innovation and improbable research. Educators and students showed that you are never too young to be a research scientist, while surprises included a Google Glass tour of the LHC tunnel.

TED is a non-profit organization that supports "ideas worth spreading" through talks of 18 minutes or less given at two annual TED conferences and posted online. TEDx (x = independently organized TED event) is a programme of local events that create a similar experience. In addition to the event on 3 May, scientists from CERN worked with animators from TED-Ed to develop films about particle physics to educate and entertain.

● All videos and animations are available online via http://tedxcern.ch.

Passport starts with a bang




The inauguration included a 54-km mountain bike rally (top left) and numerous activities including detector model-building (top right). From now on, visitors can tour the 10 stages around the LHC (bottom).

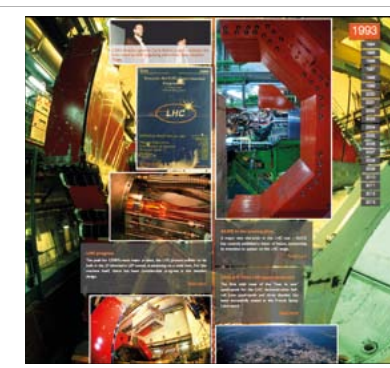
In collaboration with its local partners, CERN inaugurated "Passport to the Big Bang" on 2 June – a new, permanent, scientific tourist trail that links key points above ground around the ring of the Large Hadron Collider. Ten exhibition platforms explain the fundamental research conducted at CERN. They are located in eight French and Swiss communes and are linked by 54 km of sign-posted itineraries.

The inauguration day began with a mountain-biking rally for hardened enthusiasts followed by a bicycle tour for families. In the afternoon a myriad of attractions at all stages of the circuit included oriental dance, reptiles, music schools, cryogenic demonstrations, building detectors from Kapla and much more.

With the route now in place, visitors to the area can pick up their own passports, available in French or English from CERN and local tourist offices. They can then tour the area on foot or by bike to "stamp" their passports at the various platforms and take part in "Mission LHC" to claim their personalized reward.

● Find out more about the trail at http://passport-big-bang.web.cern.ch/en.

A new timeline for ALICE


The new online ALICE timeline traces the experiment's 20-year history.

To celebrate the 20th anniversary of the ALICE experiment, its website presents a new timeline that traces its history from 1993, when the original letter of intent was submitted, to 2013, when the first proton–lead run took place.

The timeline highlights the connections between ALICE and other heavy-ion experiments at CERN and worldwide, as well as theoretical advancements in QCD and the understanding of strong interactions. In this way, it shows how ALICE has adapted to the developments in heavy-ion physics over the years. The timeline brings people into the spotlight, showcasing those who have contributed to the success of ALICE, from building the detector to developing the software for data collection and analysis. The result is a media-rich online resource.

● Visit http://alice20.web.cern.ch/alice20/ to view this journey of discovery.

MEDICAL PHYSICS

CERN hosts workshop on X-ray detectors for medicine

The 2nd Workshop on Medical Applications of Spectroscopic X-ray Detectors attracted 104 participants to CERN on 22–25 April. Among those attending were some 50 representatives from industry and sizeable numbers from prestigious medical schools in Europe and the US.

The scientific committee – chaired by CERN's Michael Campbell – also included key staff from major medical-equipment suppliers. Many such companies now have active internal research programmes in this new field, which has taken off in the two years since the first workshop.

The meeting started with an overview given by Norbert Pelc of Stanford University. He highlighted some of the expected benefits of spectroscopic imaging, such as improved detector quantum efficiency, dose reduction and material identification, as well as some of the remaining challenges – principally charge sharing and pile up leading to degraded spectral fidelity. The programme of talks then began with sessions on sensor materials, continuing with ASICs and image processing and concluding with pre-clinical and clinical applications.

Spectroscopic imaging should complement other modalities such as magnetic resonance imaging (MRI) and positron-emission tomography (PET). In particular, it is potentially faster, more specific and has better spatial resolution, whereas MRI provides excellent soft-tissue detail and PET is extremely sensitive. Results from a team at the Mayo Clinic, Rochester, in the US, demonstrated that spectral information could be used to classify kidney stones according to their composition. With no increase in X-ray dose, optimized treatment plans were proposed to patients, in some cases avoiding unnecessary surgery. Other researchers presented biological tracers labelled with heavy atoms (e.g. gold nano-particles), which are permitting the first functional imaging using spectral information.

There were presentations during the workshop from spin-off companies using technologies originating in high-energy physics at CERN, IN2P3 in France, INFN in Italy, the KTH Royal Institute of Technology in Sweden and the Paul Scherrer Institute in Switzerland. Taking advantage of the location at CERN, participants also appreciated a talk by John Ellis on the physics of the LHC and beyond, as well as a presentation on the ATLAS experiment by Markus Nordberg and a visit to the site of the detector.

The workshop summary talk was given by Anthony Butler of Christchurch, New Zealand, a member of the team developing the Medipix All Resolution System (MARS), which is a small-animal scanner. He concluded that "spectral molecular imaging" will provide clinicians with novel data for diagnosis.

VISITS

David Willetts, centre, the UK's minister for universities and science, visited CERN on 9 April. He is seen here in the ATLAS cavern with, left to right, **John Womersley**, chief executive of the UK's STFC, **Dave Charlton**, ATLAS collaboration spokesperson, **Paul Collier**, head of the beams department, and **Sarah Gillett**, the UK's ambassador to Switzerland.

The minister of communications, science and technology of Lesotho, **Tseliso Mokhosi**, came to CERN on 17 May. His time at the laboratory included a tour of the ATLAS visitor centre and underground experimental area.

Leoš Heger, the minister of health of the Czech Republic, was one of several important visitors to CERN on 21 May. His visit included a tour of the LHC superconducting magnet test hall and the LHC tunnel, as well as ATLAS and the Antiproton Decelerator.

The minister of health for Greece, **Andreas Lykouretzos**, was another visitor to CERN on 21 May. His tour included the CMS underground experimental area as well as the LHC tunnel.

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

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

Also on 21 May, **Viliam Čislák**, left, the state secretary of the ministry of health of the Slovak Republic, came to CERN. He was welcomed by **Rolf Heuer**, the director-general, seen here presenting the state secretary with a temperature-sensitive mug showing the history of the universe.

The Turkish minister of health, **Mehmet Müezzinoğlu**, left, visited CERN on 22 May. During his visit to the CMS underground experimental area, he was presented with a book of the experiment by **Tiziano Camporesi**, deputy spokesperson of the CMS collaboration.

On 4 June, **Elio Di Rupo**, the prime minister of Belgium, left, visited CERN accompanied by groups of Belgian school students. His tour included the CMS underground experimental area with theoretical physicist **François Englert** of the Université Libre de Bruxelles, centre, and **Joe Incandela**, the spokesperson for the CMS collaboration.

Tissa Vitharana, Sri Lankan senior minister of scientific affairs, right, toured the LHC tunnel during his visit to CERN on 5 June. He was accompanied by CERN's international relations adviser **Rudiger Voss**, left, and vice-president CERN Council, **Walter Van Doninck**.

NEW PRODUCTS

The president of Austria, **Heinz Fischer**, second from right, with spouse, centre, and the Austrian minister for science and research, **Karlheinz Töchterle**, right, came to CERN on 11 June. Their visit included a tour of CERN's Antimatter Decelerator with AEGIS collaboration spokesperson **Michael Doser**, left.

Lake Shore has announced the introduction of its Model 121 programmable DC current source, which will replace a range of existing current sources. The Model 121 current source is intended for testing, measuring, and operating resistive and semiconductor devices such as diodes. The Model 121 provides a low-noise, highly stable DC current source with six decades of output current, operator-selectable or programmable in the range 100 nA – 100 mA, a large LED display and a USB interface for integration with automated test systems. For more details, contact sales@lakeshore.com or visit www.lakeshore.com.

Murata has introduced the UDQ series of isolated digitally controlled DC/DC converters. Incorporating a 32-bit ARM7 processor, the 420 W regulated UDQ2204/001 model is the first in a series of DC/DC converters from Murata to include a PMBus-compatible digital interface. The UDQ is an isolated, fully regulated, quarter brick supporting the TNV input-voltage range of 36–75 V with a typical efficiency of 95.5%. The PMBus interface facilitates monitoring of input and output voltages and currents, as well as operating temperature. For more details, contact Aya Tonooka, tel +44 1252 811666, e-mail atonooka@murata.co.uk or visit www.murata.eu.

RST has announced the 4th generation of its cable glands that also protect sensitive plant from electromagnetic interference, ensuring their uninterrupted operation. The new Euro-Top EMC contact system facilitates quick and safe cable connection by remaining open and allowing the stripped cable to be pulled through. The new generation meets the requirements of protection types IP68 and IP69K for the entire gland range. For more details, contact Oliver Kalmey, tel: +49 5407 8766–12 or e-mail oliver.kalmey@rst.eu.

Telonic Instruments has introduced a new range of low-cost high-performance benchtop digital oscilloscopes manufactured by Rigol Technologies. Designated the DS-2000 series, the range consists of three oscilloscopes with a bandwidth of 70 MHz (DS2072), 100 MHz (DS2102) and 200 MHz (DS2202). The 8-inch (800 mm × 480 mm) wide colour WVGA screen enables easy viewing of waveform displays. For more details, contact Bob or Doug Lovell, tel: +44 118 9786911 or e-mail doug@telonic.co.uk.

OBITUARIES

Massimiliano Ferro-Luzzi 1932–2013

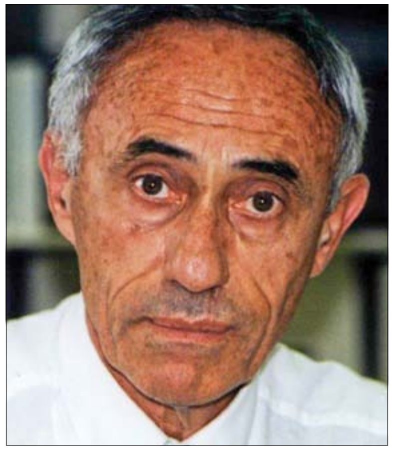
Massimiliano (Max) Ferro-Luzzi, a well known CERN physicist, passed away on 18 March. His contributions to particle physics span a period of more than 40 years.

Max grew up in Asmara (Eritrea) and studied at Rome University, where he joined the nuclear-emulsion group of Edoardo Amaldi and graduated in 1955. Here, he investigated antiproton reactions in emulsions exposed at Berkeley's Bevatron, where antiprotons had just been produced for the first time.

From the start – and throughout his career – Max combined careful analysis of data with special attention to technical improvements (in this case the automation of track measurement) and better instruments. With the scarce statistics available then, no unexpected features showed up but the observation of a first candidate for the decay of a $\bar{\Sigma}^+$ seems to have marked the beginning of Max's interest in strange baryons, including the Y^* hyperons, as they were known in those days.

Starting in 1960, he spent three years at Berkeley as a National Academy of Sciences fellow in Luis Alvarez's legendary group. He analysed the pictures of the 15 inch hydrogen bubble chamber exposed to a K^- beam. With the $\Lambda(1520)$ and $\Sigma(1660)$, he began a fruitful career as a discoverer of hyperon states. By carefully analysing data collected in $\Lambda(1520)$ formation in K^-p interactions, he was also able to determine – together with Bob Tripp and Mason Watson – the $Kp\Sigma$ parity. This result, when put together with previous knowledge on the $Kp\Lambda$ parity, indicated that the $\Sigma\Lambda$ parity was even. This was a key test for SU(3) symmetry because, if the Σ and the Λ are to be assigned to the same SU(3) octet, they must have even relative parity. The issue was settled definitely one year later by another team, in an experiment at CERN that measured directly the $\Sigma\Lambda$ parity to be even.

In 1963 Max moved to CERN, where he spent the rest of his working life – with the exception of a sabbatical year at SLAC in 1976. As one of the leaders in the Track Chamber division, he continued to analyse



Max Ferro-Luzzi. (Image credit: D Drijard.)

Kp and Kn interactions in hydrogen and deuterium bubble chambers. His most important contribution using data from bubble chambers was the discovery and study of baryonic resonances, especially the elucidation of hyperon resonances. For this he organized several successful European collaborations, for example the CERN-Heidelberg-Saclay (CHS) collaboration that for a decade was the world champion team for studying KN two-body interactions below an incident momentum of 2 GeV/*c*. Again, the systematic studies of Y^* formation were the basic ingredient for fully establishing SU(3) symmetry and the quark model.

In the late 1960s Max was among the first to realize the need to move to electronic detectors. "In this twilight of the old fashioned hadron spectroscopy," as he put it, Max formed a small group of counter- and bubble-chamber physicists who from 1970 to 1980 focused – by purely electronic means – on a high-statistics study of low-energy hadron elastic-scattering and the search for structures. Here, he pioneered a number of new techniques in multiwire proportional chambers and ultraviolet Cherenkov-light detection.

Max then turned for a while to weak interactions and neutrinos, first in 1984 with an experiment at CERN's Proton Synchrotron, then in 1986 at the Alternating Gradient Synchrotron in Brookhaven, using Conversi flash tubes. He also conducted some tests of the first prototype for the ICARUS neutrino detector. Narrow resonances were again at stake from 1989 onwards, this time in $\bar{p}p$ annihilations in the JETSET experiment at the Low-Energy Antiproton Ring (LEAR), with an emphasis on $\bar{p}p \rightarrow \phi(1020)\phi(1020) \rightarrow 4K$. Various particle-identification devices were used to cope with the four-kaon final state, including a variant of the ring-imaging Cherenkov detector designed specially for this purpose.

When LEAR ceased operation in 1995, Max joined the DIRAC collaboration, looking for the formation of $\pi\pi$ atoms, and led the CERN group that played an important role in setting up and carrying out the experiment. He also took care of the design and implementation of the ionization hodoscope and trigger at the core of the detector. Overall, the first steps of the experiment greatly benefited from his participation and guidance.

Max was a member of the Proton Synchrotron and Synchrocyclotron Committee in 1981 and the scientific secretary of the Research Board in the years 1984–1997. He retired from CERN in 1997.

Intellectually rigorous yet tempered by a degree of pragmatism in interpreting experiments, Max was a keen advocate of linguistic precision. The papers reporting his own results are models of the kind. He also took great care in presenting physics in an "organized", pedagogical way, as shown by his review papers and summer-school courses. He had a highly individual view of the world. He used to "call a spade a spade" and could be blunt but his steps were always those of a prudent, correct and rigorous person.

Max was a remarkable physicist. His friends loved him: his death is a hard loss for them.

● *His colleagues and friends.*

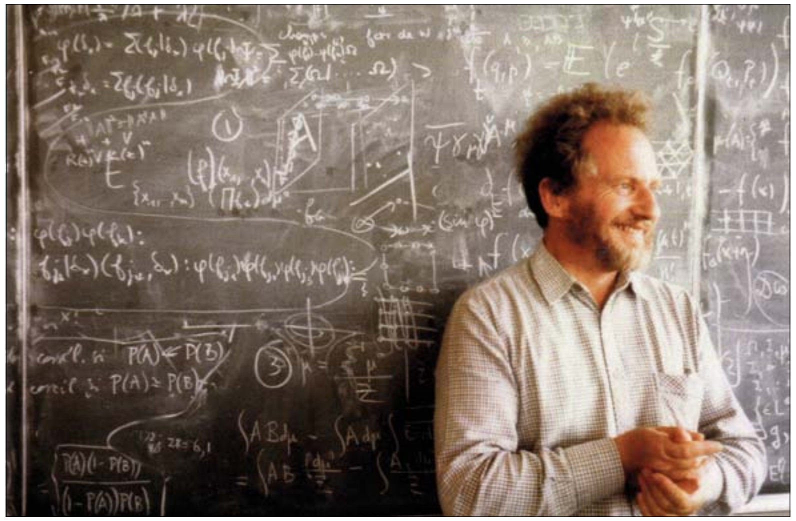
Jean-Jacques Loeffel 1932–2013

Jean-Jacques Loeffel passed away from Alzheimer's disease on 22 April. He was 80 years old.

Jean-Jacques was born in the "Jura bernois" in Bienne. He studied at ETH Zurich and began working on a PhD under Wolfgang Pauli. However, Pauli died at the end of 1958 so it was Res Jost who became his supervisor. In autumn 1962, Jost sent Jean-Jacques to CERN and it was then that we in the Theory Division discovered his immense talents. He played a major role in the collaboration that led to the KLM (Toichiro Kinoshita, Loeffel and André Martin) paper. This considerably improved the fixed-angle bound on the high-energy scattering amplitude compared with the previous result of Marcel Froissart, assuming the Mandelstam representation.

Jean-Jacques then travelled to various places: Dubna (where he spoke French with Nicolai Bogoliubov and learnt a little Russian), Seattle, New York University, the Institute for Advanced Study in Princeton and Orsay – where he acted as a neutral negotiator between students and professors during the events of May 1968, but nevertheless produced a fundamental paper on the "inverse problem" at fixed energy (the reconstruction of a potential from the scattering amplitude). Last, he returned to Switzerland and – after some time – became professor at the University of Lausanne, teaching also at the École Polytechnique Fédérale de Lausanne. He was a rigorous teacher and published relatively few papers but they were all of a high level.

He was sharp, deep and sometimes quick,



Jean-Jacques Loeffel. (Image credit: Liliane Loeffel.)

as illustrated by the following example. There were meetings between physicists and mathematicians in Strasbourg every year. On one occasion, Arthur Wightman (who died not long ago), said that his student, Barry Simon, was convinced that Carl Bender and Tai Tsun Wu had made a mistake in their treatment of the anharmonic oscillator. On the train back to Switzerland, Jean-Jacques took a piece of paper and in three lines proved that it was Simon who was wrong. This led to important results on the bound states of the anharmonic oscillator. Jean-Jacques also did excellent work on Borel summable functions and on Bethe lattices, illustrating the diversity of his interests.

Jean-Jacques was not only immensely cultured in mathematics and physics but also in literature, philosophy, religion, mineralogy, botany, ornithology and amateur astronomy. He liked art, including modern art and music: he sang in the Bach choir in Lausanne with his wife, Liliane. In short he was a perfect *honnête homme*. He also liked to make his friends taste excellent Vaudois white wines.

For all of us, his passing is a great loss.

● *André Martin, CERN.*

Albert (Bacco) Messiah 1921–2013

Albert M L (Bacco) Messiah died on 17 April 2013 in Paris. He had a remarkable life, both as a physicist and educator who wrote the first books on modern quantum mechanics from which two generations of French physicists learnt quantum mechanics and as a member of the Free French Army during the Second World War.

Albert Messiah was born in Nice on 23 September 1921. At the start of the Second World War, he and his brother André were studying at the Ecole Polytechnique in the north of France. Their uncle hired them to drive himself and his wife to San-Jean-de-Luz in the south-west of the country where they hoped to be sheltered from the Nazis. After hearing a radio talk by Marshal Pétain during the drive south – and realizing that Pétain would not resist the Nazis – Messiah resolved to leave France, expecting to fight the Germans in Africa. He joined a group of Poles on a ship that he thought would go to Africa. Instead the ship went to London where Messiah joined Charles de Gaulle and the Free French forces.

In September 1940 Messiah joined an expedition to Dakar that failed to liberate the French colony from the Vichy French military forces who actively opposed the Allies. At the end of 1944 he joined the 2nd Armored Division in the liberation of Strasbourg and was part of the allied advance into Germany. He was in the unit that occupied Berchtesgaden and he took trophies, including Hermann Goering's briefcase and Adolf Hitler's ruler, both of which he later donated to the Museum of the Liberation.

Having been a French Jew who escaped France to fight in the Free French Army of de Gaulle, he was awarded a grant to study

Faces & Places

and work at the Institute for Advanced Study, Princeton, in the US. The seminars at the institute were incomprehensible to Messiah, who had only a high-school education in physics, and he became depressed to the extent that he considered abandoning his plans to become a physicist. Fortunately he met Robert Marshak at a meeting of the American Physical Society in Washington, DC. Marshak suggested that Messiah move to the University of Rochester and work for a US PhD in physics.

When Messiah returned to France, he taught quantum mechanics at the French Nuclear Centre at Saclay. There was no text on quantum mechanics in French until he wrote his two-volume *Mécanique Quantique*, published by Dunod in 1959. His books were translated to English by G M Temmer, as well as to other languages. The books were the standard references in

Albert "Bacco" Messiah. (Image credit: Janine Messiah.)

French on quantum mechanics for many years. Messiah later became the director of the physics division at the French Atomic Energy Commission and a professor at the Pierre and Marie Curie University in Paris.

Messiah collaborated with Oscar Greenberg on identical particle statistics other than bosons or fermions. This work led directly to Greenberg's suggestion of parastatistics of order 3 for quarks, which was the first suggestion that quarks carry a hidden three-valued charge, now colloquially called "colour".

Messiah's first wife Jacqueline, died suddenly in 1962. He then married Janine Grenier in 1964. He has three children, Martine, Antoine and Pierre Henri, as well as four grandchildren.

We will remember Bacco for his warmth and kindness, for his sense of humour and for the depth of his understanding of physics.

● *O W Greenberg, University of Maryland.*

Perihan Tolun 1934–2013

Perihan Tolun, the first experimental particle physicist at the Turkey and Middle East Technical University (METU), passed away on 27 May in Istanbul at the age of 79.

Perihan Tolun graduated in the top rank from the science branch of Arnavutköy American College for Girls, a renowned high school in Istanbul, in 1955. She then came first among the physics applicants for a Rockefeller scholarship to study abroad for an advanced degree. She used the scholarship to go to Bristol University, where she earned her BSc in 1961 and a PhD in 1966. While in Bristol, she worked in Cecil Powell's group, participating in experiments at the Proton Synchrotron, which is how her association with CERN began.

Perihan Tolun. (Image credit: M and N Simuhin.)

Following invitations from the eminent Turkish physicists Erdal İnönü and Feza Gürsey, Tolun joined the Physics Department at METU, Ankara, in 1966. She spent the rest of her career there until her retirement in 2001, with periods as a research associate at Yale University (1970–1971) and CERN (1976–1977). She was remained an active researcher at METU until the beginning of 2013, just before her illness was diagnosed.

At METU, Tolun started the first group in experimental particle physics and set up a laboratory where manual stereo microscopes were installed for analysis of elementary-particle tracks in plates of photographic emulsion. The lab was then equipped with an automatic microscope system, in which a CCD camera reads out the image for the CHORUS experiment. A new system was later developed for the OPERA experiment in the Gran Sasso National Laboratory.

Tolun's first experiment at CERN, with Powell's group for her PhD, involved the measurement of the magnetic moments of the Λ^0 and Σ^+ hyperons. After she joined METU in 1966, under her leadership the group from Ankara collaborated with CERN, Lausanne, Munich and Rome in the subsequent experiment, making precision measurements of the magnetic moment of the Λ^0 hyperon. In 1977, her group joined the WA17 experiment, measuring the lifetime of charmed hadrons produced in neutrino interactions. From 1991 onwards, her participation in the CERN neutrino programme continued with the CHARM II and CHORUS experiments, with significant Turkish contribution, especially in CHORUS. Following her lead, after the CHORUS experiment, METU joined the OPERA collaboration.

Tolun was highly respected: she was compassionate, courteous, thoughtful and candid. She dedicated her life to science and her passing away is a great loss to the particle-physics community in Turkey. She will be remembered by her students and colleagues as a brilliant researcher, inspiring teacher and adviser.

● *Mehmet Zeyrek, METU/Ankara.*

Recruitment

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- Co-supervision of master and PhD students

Requirements
- Studies of physics or engineering with a PhD degree
- Long-term experience in accelerator physics
- Expert knowledge of experimental techniques and data analysis in accelerator science
- Experience in computer simulations and numerical methods

For further questions contact Dr. Ralph Aßmann, phone +49 40 8998-3187, ralph.assmann@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. People with disabilities 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.

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Human Resources Department | Code: EM066/2013
Notkestraße 85 | 22607 Hamburg | Germany
Phone: +49 40 8998-3392 | Email: recruitment@desy.de
Deadline for applications: 25th July 2013
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- Study realistic applications of new accelerator technologies for photon science and particle physics, prepare new proposals and present them in various committees in- and outside of DESY
- Help in the supervision of master and PhD students

Requirements
- Studies of physics or engineering with a PhD degree
- Several years of experience in accelerator, nuclear or particle physics
- Knowledge of experimental techniques and data analysis in accelerator or particle detector physics
- Experience in computer simulations and numerical methods

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Human Resources Department | Code: EM067/2013
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Phone: +49 40 8998-3392 | E-mail: recruitment@desy.de
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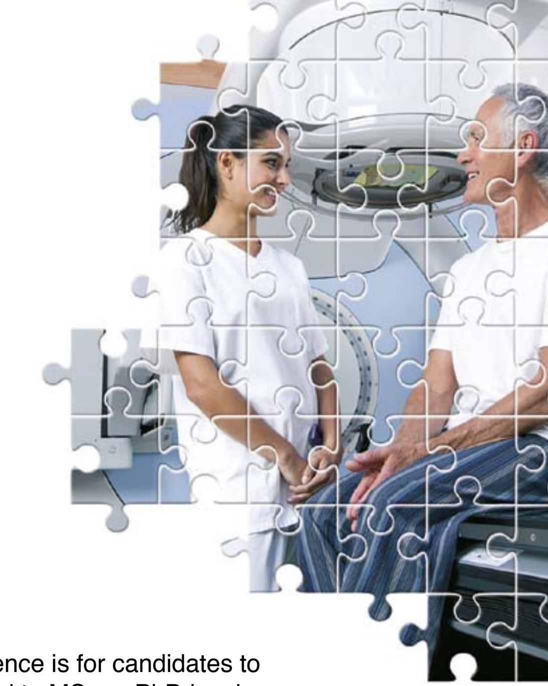

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Bookshelf

Summer Bookshelf

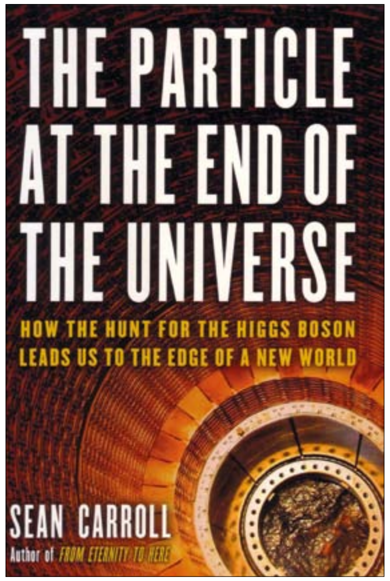
Summer is the season of conferences for physicists with holidays squeezed in where possible. For those with time for reading something other than drafts of their latest papers and preprints with new results, this Bookshelf features a few books for more relxed reading – or for recommending to family and friends while the hard work continues.

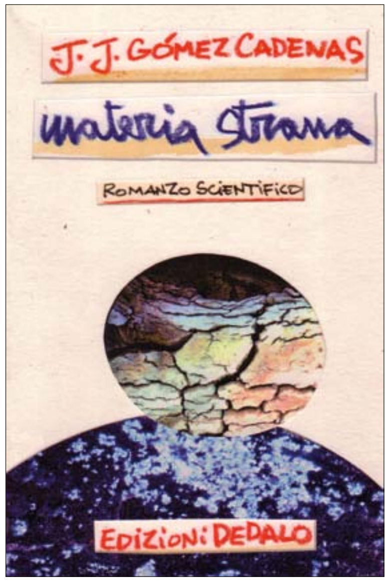
The Particle at the End of the Universe

By Sean Carroll
Oneworld
Hardback: £16.99
Paperback: £9.99

In his latest book, Sean Carroll, author of the brilliant *From Eternity to Here*, has produced an accessible read aimed at the layperson interested in an up-to-date account of the state of particle physics and, in particular, the discovery of the Higgs boson. Carroll is well placed to offer the reader an in-depth view of the world of particle physics, being close enough to give a personal account yet maintaining the perspective of an onlooker. As a result he is a superb advocate of the case for "Big Science", which he demonstrates to full effect in both the opening and closing chapters of the book, beginning with several snapshots of physicists celebrating the milestones that led up to the announcement of the major discovery at CERN on 4 July 2012.

By interweaving the scientific concepts with chapters on historical, social and political aspects of particle physics, Carroll dilutes the hard bits with human interest, appealing to the widest possible audience. He conveys the central importance of the Higgs discovery before going into the theory in any detail, so that we get an idea of what the fuss is about. He explains that the particle at the end of the universe is not a reference to the Higgs boson's location in space or time but rather its location in our understanding, as the final piece of the Standard Model. This marks the end of the journey to describe our everyday surroundings and the beginning of a new era of full discovery. The theme is developed further when Carroll gets into his stride with dark matter, supersymmetry and string theory, demonstrating how the Higgs particle can act as a portal for exploring as yet unreachable phenomena.





True to the headline-grabbing comments of intrigue and drama in high-energy physics on the cover, the book recounts the chequered history of accelerators: the engineering challenges and the agonies of having your machine switched off when a major discovery could be just around the corner; or the frustrations of not getting the machine built at all, as with the Superconducting Super Collider. In this way, the account does justice to the magnitude and achievements of the LHC and its experiments.

What is meant by the "discovery" of a particle is also explained clearly, together with the issues concerning the timing and control of such announcements, especially given the high level of public interest. Concerning the difficulties of apportioning credit, Carroll proposes that scientific collaborations should be allowed to win the Nobel prize and that "Whoever gets that rule change implemented might deserve the Nobel Peace Prize".

A couple of errors should be mentioned: the Higgs boson is repeatedly credited with distinguishing the electron from the neutrino and the up quark from the down, etc. The important qualification that this statement holds true only for the left-handed components of these particles is mentioned only latterly. Also, there is an unfortunate sign error in the diagram of Fleming's left-hand rule – not a big deal in itself but enough to undermine confidence in the book for some readers, perhaps giving the impression that it has been rushed into print.

With this book Carroll consolidates his position as an exceptionally talented writer of difficult physics concepts for the layperson. He weaves together fascinating facts, amusing anecdotes and insightful analogies. In storyteller style, with colourful characters and thrilling plots, he propels the reader along the journey that particle physics has made in our lifetime. The layperson can empathize with the emotional highs and lows of research, the patience and tenacity required to bring a project like the LHC to completion and the laudable level of co-operation that the particle-physics community demonstrates to other large and complex organizations – to quote: "If only the United Nations could work like CERN, the world would be a better place."

● *Theresa Harrison, Ilmington.*

Materia Strana (Strange Matter)

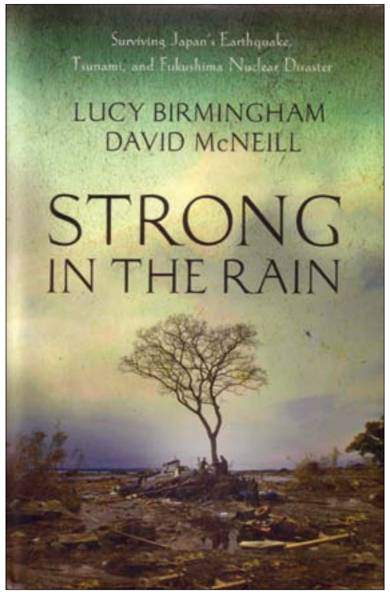
By J J Gómez Cadenas, translated from the original Materia Extraña, published by Espasa Calpe
Edizioni Dedalo
Paperback: €16

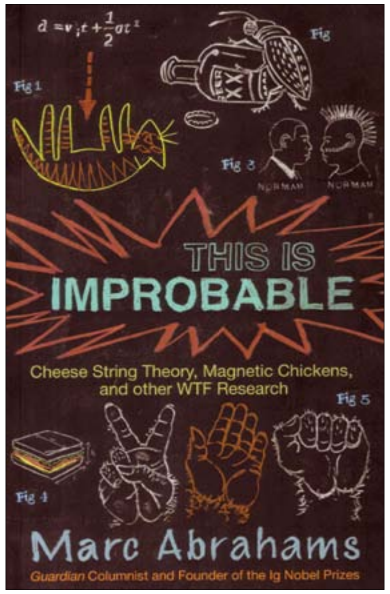
CERN has attracted the attention of a number of writers as a stage for their thrillers and in most cases they have been assisted on the scientific background by friends or by interviews with key CERN scientists. In Dan Brown's *Angels & Demons*, CERN's science portfolio was an excuse for writing a science-fiction novel in which special effects overshadow reality to create shocking situations. Bruno Arpaia's *L'Energia del Vuoto* (*Vacuum's Energy*) was more respectful of CERN's science, providing detailed scientific descriptions but with the risk of breaking the rhythm of the novel (*CERN Courier* December 2011 p59). By contrast, J J Gómez Cadenas has been gifted with a rare combination of talents: he is a good writer and a professional particle physicist (*CERN Courier* March 2013 p23). As a result, *Materia Strana* is a powerful thriller based on an almost realistic scientific case that fits well with an engaging narration.

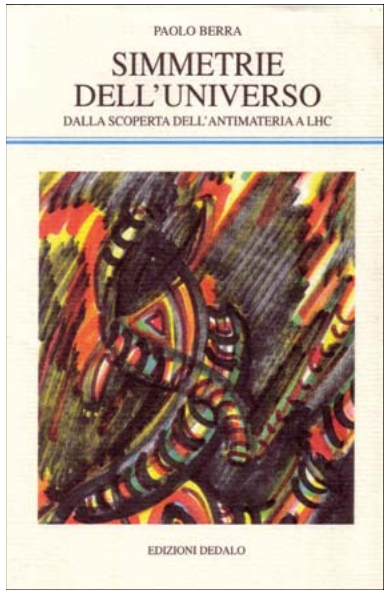
The possible existence of stable strange matter in the universe was put forward by Edward Witten and independently by Álvaro De Rújula and Sheldon Glashow in 1984. Some neutron stars could, indeed, be strange stars. The possibility that high-energy ion–ion collisions could create chunks of strange matter that would have a tendency to grow exponentially in size was debated when the Relativistic Heavy-Ion Collider started operating in the US. The probability of this happening has been calculated to be negligibly low but in *Materia Strana* it is assumed to be much higher – dangerously high for a high-luminosity, ion–ion LHC at CERN.

This is the main theme around which a truly international thriller develops involving Irene, the gifted young theoretician with Iranian roots and Héctor, an amazing experimental physicist from the US with multiple backgrounds as a boxer, soldier and scientist, who becomes involved in a highly dangerous mission in Iran – as well as with Irene. There is also Friedrich, the powerful but unscrupulous head of the large experiment that is likely to bring him the Nobel prize; Helena, the hyper-efficient, fighting and bright director-general of CERN; and Boiko, a natural-born killer, who escaped to Geneva from the horrors of Chernobyl and Grozny. The deadly fight between Hector and Boiko has the intensity of the pages of Khaled Hosseini's *The Kite Runner*. Intermixed with dreams and ghosts crossing the border between life and death, these stories provide the texture for a decent thriller where good wins eventually over evil, although with a heavy toll.

● *Roberto Battison, University of Trento.*







Strong in the Rain

By Lucy Birmingham and David McNeil
Palgrave Macmillan
Hardback: £17.99 $27.00
E-book: $12.99

Some dates will remain in the public consciousness forever, given their cultural impact. Personally, these would include 11 September 2001 (the attacks on the twin towers in New York), 7 July 2005 (the London Underground bombings) and 11 November (Armistice Day, commemorating the end of the First World War).

On 11 March 2011 the Tōhoku earthquake occurred approximately 70 km off the coast of Japan. It was the most powerful earthquake ever to hit Japan and the fifth most powerful to be recorded since records began in 1900. The earthquake triggered powerful tsunami waves that reached heights of up to 40 m. The Japanese National Police Agency subsequently confirmed 15,883 deaths, ensuring that this date will live long in the Japanese cultural memory.

Strong in the Rain brings together six stories from people affected by the tragic events associated with the earthquake/tsunami on 11 March. The book is described as "part history, part science" and the authors use the experiences of the six people in the book, in addition to their own, to paint a tale of heroes and villains.

The book gets off to a slow start but the reading becomes gripping once the stories move on to the tales of the six central protagonists. It delves into the Japanese cultural strengths and weaknesses in equal measure, from the lack of information provided regarding the nuclear meltdown at the Fukushima Daiichi to the best qualities of the Japanese spirit and character, which are embodied in the town mayor who changes press coverage of the nuclear meltdown with a heartfelt plea uploaded to YouTube.

Living somewhere like the UK it is hard to picture the epic scale of this disaster but the authors weave between the stories of the protagonists to make you feel like you were there. The book manages to be both heart-breaking and uplifting in equal measure and the title *Strong in the Rain* – taken from a famous Japanese poem – becomes an apt description of the events that unfold.

Some books portraying historical events have the potential to become dated but I believe that *Strong in the Rain* will stand

Bookshelf

up well to the test of time. This is mainly because of the human stories within the book that leave you questioning how you might have behaved under similar stress. What would you leave and who would you save? What does it take to be a hero? It also leaves you thinking how important learning from the past is to save us all in the future. I would heartily recommend this book and will be lending it to all of my friends.

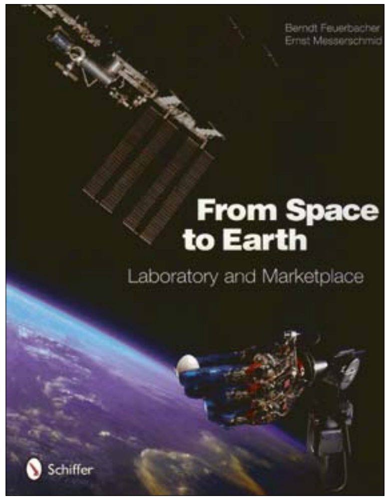
● *Steve Pritchard, University of the West of England.*

This is Improbable: Cheese String Theory, Magnetic Chickens and other WTF Research
By Marc Abrahams
Oneworld
Paperback: £8.99

Anyone from CERN who attended the *Ig Nobel* show in Geneva in May, or goes to the real Ig Nobel Awards ceremony in Cambridge, Massachusetts, every autumn will know why they should acquire this book. For those who did not and do not, Marc Abrahams is the editor of the *Annals of Improbable Research* and the founder of the Ig Nobel Awards. He is also a columnist for the *Guardian* and here I declare an interest: he is a friend and this book is a collection of his *Guardian* columns. But even if I did not have an interest to declare, I would say the same thing about this rich assembly of risible research.

If you want to know more about the air-conditioning capacity of the human nose (a paper published in the *Annals of Biomedical Engineering*) or why European washing machines tend to walk across the room (*Journal of Sound and Vibration*) or why an 18th century Bishop of Durham is survived by his rectum (no longer attached to the bishop, it is pickled in a jar at the Hunterian Museum of the Royal College of Surgeons in London), then this is the book for you. You can also learn about the effect of mobile phones on sexual behaviour in rabbits; medical uses for tea bags; and the effect of garlic bread on family interaction.

In 2002 doctors in Bristol warned in the *BMJ* that just watching sport could be a health hazard: "Risk of admission for acute myocardial infarction increased by 25% on 30 June 1998 [the day England lost to Argentina in a penalty shoot-out] and the following two days." A team in Lausanne reported in the *International Journal of Cardiology* that sudden cardiac deaths were up 63% during the World Cup, compared with an equivalent period a year earlier when there was no World Cup. These things balance out: in the journal *Heart*, two French doctors wrote a paper entitled "Lower Myocardial Infarction Mortality in French



Men the Day France Won the 1998 World Cup of Football." This is a healthy helping of scholarship served with a light heart.

● *Tim Radford, science editor of the* Guardian *until 2005.*

Simmetrie dell'universo: Dalla scoperta dell'antimateria a LHC
By Paolo Berra
Edizioni Dedalo
Paperback: €16

Paolo Berra is a nuclear engineer who worked for many years at CERN before going on to do an MBA at Harvard. His background and education are so diverse that it was difficult to know what to expect from his book for the general public about the symmetries of the universe. However, I think that the result of this "experiment" turns out to be a success.

The book starts with a general introduction to the physics of the 20th century: Paul Dirac, Erwin Schrödinger, Albert Einstein and the theories that revolutionized our vision of the universe. The author then goes on to talk about the Standard Model, Richard Feynman, symmetries, unification theories, black holes and other mysteries that the universe is still hiding from researchers. This journey through the history of science and its leading figures ends with part three of the book. The fourth and last part breaks with the narrative as the author focuses on the machines that are necessary to explore what he calls "Big Science".

I liked the first three parts a great deal. The language is clear and the logical links between various historical periods and scientific findings across the years are emphasized, making the reading particularly interesting. In addition, the author presents difficult theoretical topics in an accessible way that I really appreciated.

The fourth part is where I was expecting the most from the author, as I knew he had worked at CERN to develop machines to be used for hadron-therapy, the medical technique that uses particle accelerators to treat tumours. However, although he is clearly at ease with the topics (there are fewer references to other publications) and the quality of the writing remains high, I thought that he would have had much more to say. My curiosity is therefore not entirely satisfied – which should be interpreted as an invitation to the author to write a second book soon.

● *Antonella Del Rosso, CERN.*

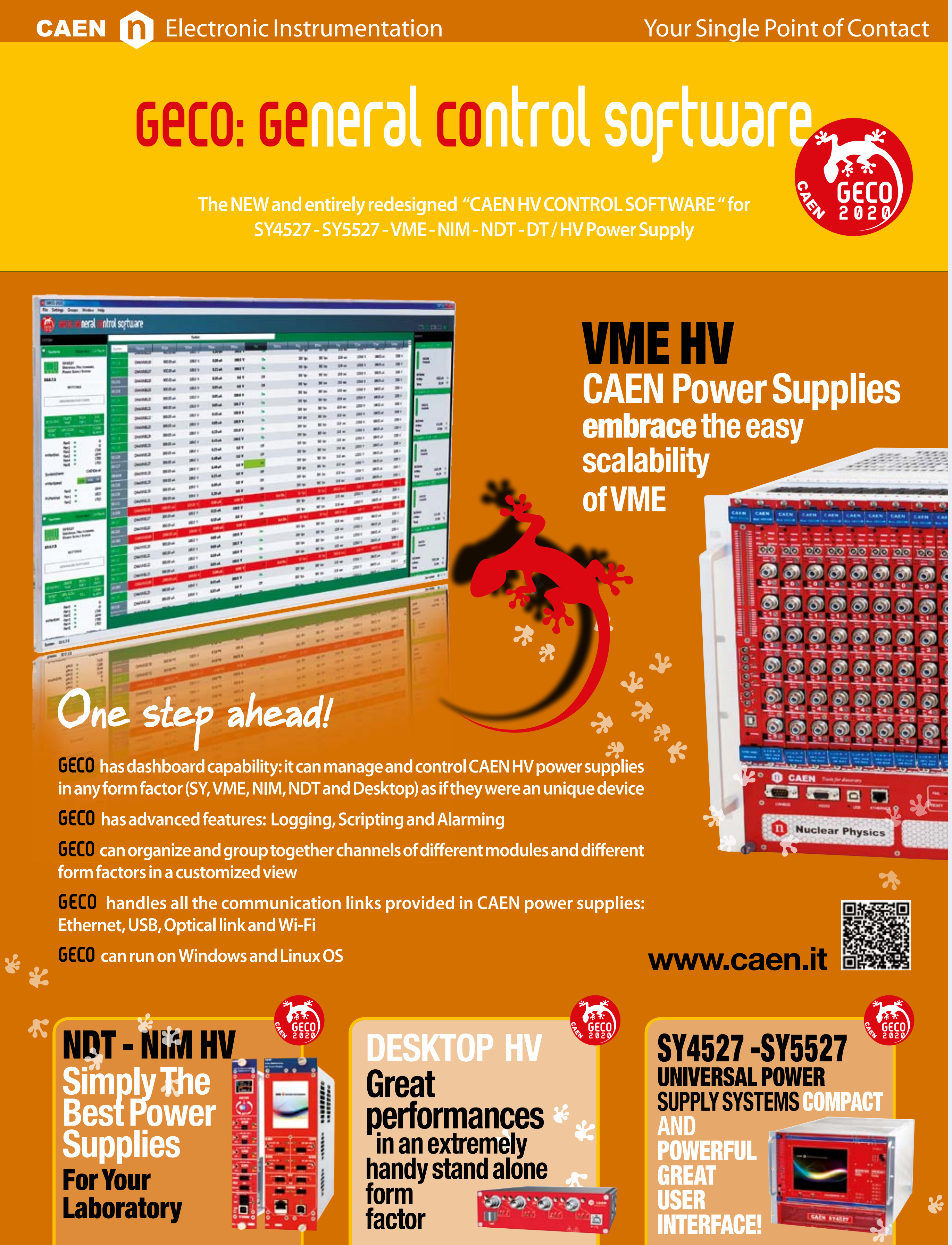
From Space to Earth: Laboratory and Marketplace
By Berndt Feuerbacher and Ernst Messerschmid
Schiffer
Hardback: £32.50 €39.90 $39.99

If unlocking the subatomic world was a defining aspect of the first half of the 20th century, then the opening up of our neighbourhood in space took on a similar mantle during the second half. With the launch of Sputnik 1 in 1957, the space age began. More than 50 years on, "space" is now part of daily life – think of satellite broadcasting and GPS systems – but it continues to excite.

First published in German as *Vom All in den Alltag* (Motorbuch 2007), *From Space to Earth* charts the achievements of half a century of space flight. It does this not so much in chronological order but in sections on, for example, space in everyday life, exploration of the solar system and the work of astronauts in space. This brings back memories for older readers – from Sputnik-spotting through the first Moon landings to amazing views of Jupiter and Saturn relayed by the *Voyager* spacecraft and incredible landscapes seen through the eyes of Mars rovers.

However, it is the younger generation – the future astronauts, space engineers and scientists – who the authors have firmly in their sights. Highly experienced in space flight and space science, they started out as physics students – Messerschmid was a CERN fellow who became an astronaut (p28 of this issue). So they are well placed to include side texts that explain the physics behind the achievements. For those who want to join in, pages describe what it takes to be an astronaut, while the final chapter looks into the future and the possibility of space colonization – something that the authors see as inevitable, given the technology.

● *Christine Sutton, CERN.*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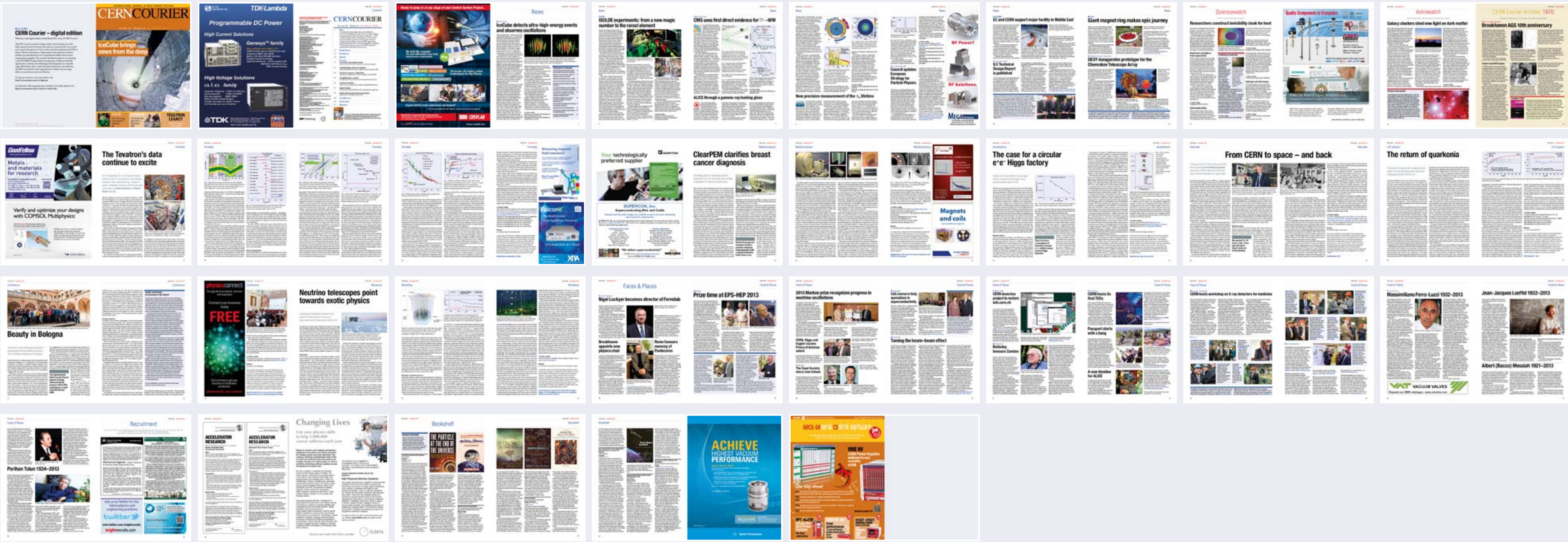

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VOLUME 53 NUMBER 6 JULY/AUGUST 2013

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