WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the July/August 2014 issue of *CERN Courier*.

In July 1964, the results of an experiment with neutral kaons at Brookhaven Laboratory took particle physicists by surprise when it discovered CP violation – a subtle difference between particles and antiparticles. This issue takes a look at the discovery and some of what followed at CERN. In particular, the NA31 and NA48 experiments played a leading role in the discovery of direct CP violation, which helped to understand the phenomenon in the context of the Standard Model of particle physics. Fifty years later, interest in the effect shows no sign of abating, especially after CP violation was also found in B mesons at KEK and SLAC in 2001. Experiments to pin down the phenomenon continue, for example, with B mesons at the LHC, and are also beginning to turn to neutrinos. The NOvA experiment at Fermilab has neutrino oscillations in its sights, as well as an initial study of CP violation.

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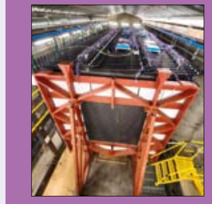
INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 54 NUMBER 6 JULY/AUGUST 2014

Fifty years of CP violation



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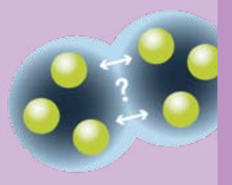

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CERNCOURIER

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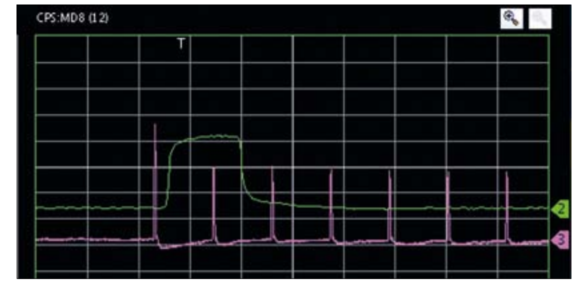
On the cover: In the 1980s and 1990s, two experiments at CERN – first NA31 and then NA42 – sent neutral kaons down the long decay tube, visible to the left, in studies that led to the discovery of direct CP violation in the particles' decays (p23). Today, the NA62 experiment follows in their footsteps with investigations of rare kaon decays. (Image credit: CERN-EX-0304025-03.)

CERNCOURIER
Volume 54 Number 6 July/August 2014

News

CERN

LS1: beams are back in the Proton Synchrotron



Far left: The PS injection kicker (green signal) sent the first proton bunch into the accelerator on 20 June, for thousands of turns. Beam-position monitors see the bunch every time it completes one turn (purple signal). (Image credit: CERN.) Left: Jean-Phillipe Tock, the SMACC project leader, adds his signature to mark the closure of the last of 1695 outer magnet bellows, alongside Luca Bottura, group leader of magnets, superconductors and cryostats. (Image credit: CERN-PHOTO-201406-127 – 10.)

Beams of protons are back in CERN's Proton Synchrotron (PS), having circulated around the accelerator on 20 June for the first time in more than 15 months. The PS restart followed on from the restart of beam in Linac 2 and then the PS Booster (PSB) on 2 June.

The beam made it into the PS on schedule, thanks to the efforts of the PSB specialist teams, who were called upon on many occasions for hardware interventions during the preceding weeks of hardware commissioning and "cold" tests. These included fixing vacuum leaks, re-configuring timing links, correcting magnet connections and, in one instance, replacing an entire magnet with a spare, owing to a water leak. Operations, radiofrequency and instrumentation teams then needed to adjust the settings for beam acceleration and extraction from the PSB to the PS. With beam back in the PS, beam commissioning tests could begin. During this final phase, all of the beam diagnostics – from beam current to bunch spacing – need to be checked, first with low-intensity beams (10^{11} protons) before moving to higher-intensity levels (10^{12} protons). The PS will then be ready to send beams to the East Area and the neutron facility, nToF, where physics is planned to start in late July. ISOLDE, the only experimental facility connected directly to the PSB, will be the first user to receive its beams, with physics set to restart in mid-July. The physics programme in the Super Proton Synchrotron is set to restart in the autumn.

At the LHC, the teams closed the last of the 1695 outer magnet bellows on 18 June, marking the end of the Superconducting Magnets And Circuits Consolidation (SMACC) project. Leak tests on the entire machine are proceeding well, and by late June they had been completed in sector 5-6 and were under way in sector 7-8. At the same time, sector 6-7 – the first to be cooled – had reached 20 K, and will be maintained at this temperature during continuity testing of the copper stabilizer. Four sectors should be cool by the end of the summer, and all eight sectors of the LHC are scheduled to be cooled to the nominal temperature of 1.9 K in late autumn.

Beam is expected back into the LHC early in 2015, and the restart of the LHC physics programme is planned for spring 2015, with a collision energy of 13 TeV instead of the previous 7–8 TeV.

ALPHA measures charge of antihydrogen

The ALPHA experiment at CERN's Antiproton Decelerator (AD) has made a new precision measurement of the electric charge of antihydrogen atoms, finding it to be compatible with zero to eight decimal places. This is the first time that the charge of an antiatom has been measured to high precision. The ALPHA collaboration studied the trajectories of antihydrogen atoms released from the experiment's system of particle traps in the presence of an electric field. If the antihydrogen atoms had a charge, the field would deflect them. The analysis, based on 386 events, gives the value of the antihydrogen electric charge as $(-1.3\pm1.1\pm0.4)\times10^{-8}$.

● **Further reading**

C Amole *et al.* 2014 *Nature Communications* **5**; doi:10.1038/ncomms4955.

Sommaire en français

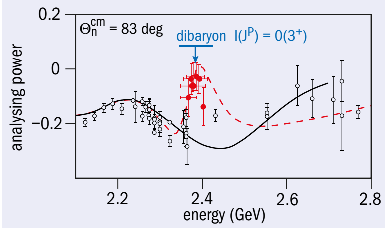
NEW PARTICLES

COSY confirms existence of six-quark states

Experiments at the Jülich Cooler Synchrotron (COSY) have found compelling evidence for a new state in the two-baryon system, with a mass of 2380 MeV, width of 80 MeV and quantum numbers $I(J^P) = 0(3^+)$. The structure, containing six valence quarks, constitutes a dibaryon, and could be either an exotic compact particle or a hadronic molecule. The result answers the long-standing question of whether there are more eigenstates in the two-baryon system than just the deuteron ground-state. This fundamental question has been awaiting an answer since at least 1964, when first Freeman Dyson and later Robert Jaffe envisaged the possible existence of non-trivial six-quark configurations.

The new resonance was observed in high-precision measurements carried out by the WASA-at-COSY collaboration. The first signals of the new state had been seen before in neutron–proton collisions, where a deuteron is produced together with a pair of neutral pions (*CERN Courier* September 2011 p8). Now this state has also been observed in polarized neutron–proton scattering and extracted using the partial-wave analysis technique – the generally accepted ultimate method to reveal a resonance. In the SAID partial-wave analysis, the inclusion of the new data produces a pole in the $^3D_3$ partial wave at $(2380 \pm 10 - i\,40 \pm 5)$ MeV.

The mass of the new state is amazingly close to that predicted originally by Dyson, based on SU(6) symmetry breaking. Moreover, recent state-of-the-art Faddeev calculations by Avraham Gal and Humberto Garcilazo reproduce the features of this new state very well. The quantum numbers favour this state as a dibaryon resonance – the "inevitable" non-strange dibaryon predicted by Terry Goldman and colleagues in 1989.



Energy dependence of the analysing power near 90°, where the maximum resonance effect occurs. Red symbols show the new measurements, and dashed and solid lines show the SAID partial-wave solution with and without resonance.

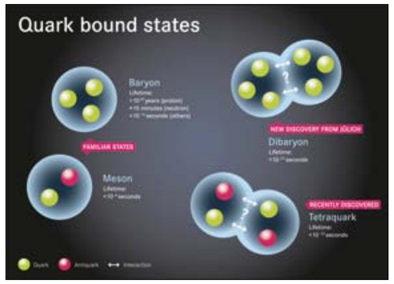


Illustration of currently known quark configurations. In addition to the standard configurations consisting of three valence quarks (baryons) or quark–antiquark pairs (mesons), there is now compelling evidence for exotic configurations. After the recent discovery of "tetraquark" systems – mesons consisting of two quarks and two antiquarks (CERN Courier *June 2014 p12) – the newly discovered dibaryon resonance points to configurations composed of six quarks. (Image credit: IKP-FZJ.)*

● **Further reading**

P Adlarson *et al.* 2014 *Phys. Rev. Lett.* **112** 202301.

JEFFERSON LAB

CEBAF delivers first beams following upgrade

On 7 May, the newly upgraded Continuous Electron Beam Accelerator Facility (CEBAF) delivered the first electron beams to its new experimental complex at the US Department of Energy's (DOE's) Jefferson Lab. The success capped a string of accelerator commissioning milestones that were needed for approval to restart experimental operations following CEBAF's first major upgrade.

CEBAF is an electron-accelerator facility that employs superconducting radiofrequency (SRF) technology to investigate the quark structure of the nucleus. The first large-scale application of SRF technology in the US, it was originally built to circulate electrons through 1–5 passes to provide 4 GeV electron beams. As a result of the operators' experience in running the machine at its peak potential, the original installation eventually achieved operational energies of 6 GeV (*CERN Courier* October 2000 p9).

In May 2012, the accelerator was shut down for its 12 GeV upgrade (*CERN Courier* November 2012 p30). This $338-million project, which will double CEBAF's maximum energy, includes the construction of a fourth experimental hall (Hall D), as well as upgrades to equipment in three existing halls (Halls A, B and C) (*CERN Courier* April 2009 p15).

Accelerator operators began the painstaking task of bringing the accelerator back online last December. By 5 February, they had achieved the full upgrade-energy acceleration of 2.2 GeV in one pass through the machine. Then on 1 April, the operators exceeded CEBAF's previous maximum energy. The accelerator delivered three-pass, 6.11-GeV electron beams with 2 nA average current onto a target in Hall A, and recorded the first data of the 12-GeV era, holding the pattern for more than an hour.

The operators continued to push the upgraded machine, and early on 7 May the energy was increased to 10.5 GeV through the entire 5.5 passes. In the last minutes of the day, 10.5 GeV beam was delivered into the new Hall D complex. Having met all of the major milestones in the 12-GeV project for the DOE approval step, Critical Decision-4A (Accelerator Project Completion and Start of Operations), staff and users are now looking forward to demonstration of 12-GeV energy and beam delivery to Jefferson Lab's experimental halls for commissioning and the start of experiments.

On 7 May, operators successfully threaded the first electron beam up the new beamline towards Hall D. (Image credit: Jefferson Lab.)

LABORATORY ASTROPHYSICS

Laser experiment simulates supernova

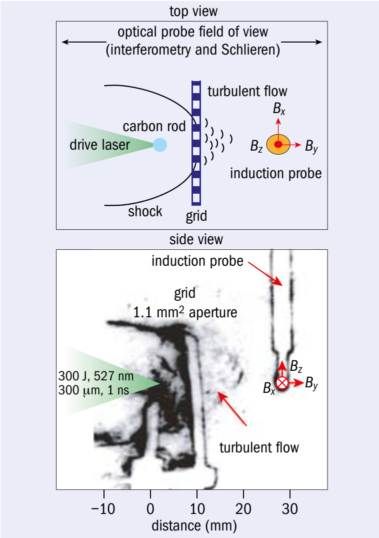
Supernova explosions, triggered when the fuel within a star reignites or its core collapses, launch a shock wave that sweeps through a few light-years of space in only a few hundred years. The remnants of these explosions are now recognized widely as one of nature's major particle accelerators. The theory is that charged particles increase in energy through repeated encounters with magnetic "mirrors" or changing magnetic fields in the shocks. Now, a team of researchers has brought some of these processes down to Earth, in an experiment to investigate the turbulent amplification of magnetic fields in the supernova remnant, Cassiopeia A, which was first seen about 300 years ago in the constellation Cassiopeia.

Radio observations of Cassiopeia A have revealed regions within the expanding remnant that are consistent with synchrotron radiation emission from giga-electron-volt electrons spiralling in a magnetic field of a few milligauss – 100 times higher than expected from the standard shock compression of the interstellar medium. The origin of such high magnetic fields, which help to make Cassiopeia A a particularly effective particle accelerator and bright radio source, appears to lie with regions of turbulence that could amplify the magnetic field and that could be related to puzzling irregular "knots" seen in optical observations. One explanation for these knots is that the shock produces turbulence as it passes through a region of space that already contains dense clumps or clouds of gas.

To investigate these possibilities, an international team led by Gianluca Gregori at Oxford University used the Vulcan laser facility at the UK's Rutherford Appleton Laboratory to focus three laser beams onto a carbon rod 0.5 mm thick in a chamber filled with low-density gas. The heat generated made the rod explode, creating a blast that expanded through the surrounding gas, mimicking a supernova shock wave. To simulate the clumps that might surround an exploding star, the team introduced a mesh of fine plastic wires 0.4 mm thick with cells 1.1 mm square at a distance of 1 cm from the rod. Using hydrodynamical scaling relations, the team can relate the experimental conditions 0.3 μs after the laser burst to Cassiopeia A as it is now, about 310 years after the supernova explosion. With the same scaling, the wire thickness corresponds to a distance of about one parsec in the remnant.

The researchers used various techniques to monitor the evolution of the shock wave, including an induction coil to measure the magnetic fields produced. The measurements show that the grid produces additional turbulent flow and gives rise to magnetic-field components that are 2–3 times larger than without it. The results are also in good agreement with the output from numerical simulation code, in particular, the magnetohydrodynamic code FLASH, developed by Don Lamb at Chicago University. The simulations reproduce well the position of the shock, the peak electron density and temperature – with and without the grid – and confirm that the magnetic field is indeed enhanced as a result of induced turbulence created as the shock moves through the grid.

These results demonstrate that the amplification of the magnetic field within the Cassiopeia A "particle accelerator" might indeed arise from the interaction of the shock with a clumpy interstellar medium. Importantly, the experiment also gives valuable confirmation of the simulations, providing for the first time an experimental means to validate the simulation codes used for many astrophysical phenomena.



Top: Diagram of the experiment with the grid in place. Bottom: Schlieren image at 300 ns after the laser shot.

● **Further reading**

J Meinecke *et al.* 2014 *Nature Physics* **10** 520.

FUNDAMENTAL PHYSICS

First direct high-precision measurement of the proton's magnetic moment sets the stage for BASE

A German/Japanese collaboration working at the University of Mainz has performed the first direct high-precision measurement of the magnetic moment of the proton – which is by far the most accurate to date. The result is consistent with the currently accepted value of the Committee on Data for Science and Technology (CODATA), but is 2.5 times more precise and 760 times more accurate than any previous direct measurement. The techniques used will feature in the Baryon-Antibaryon Symmetry Experiment (BASE) – recently approved to run at CERN's Antiproton Decelerator (AD) – which aims at the direct high-precision measurement of the magnetic moments of the proton and the antiproton with fractional precisions at the parts-per-billion (ppb) level, or better.

Prior to this work, the record for the most precise measurement of the proton's magnetic moment had stood for more than 40 years. In 1972, a group at Massachusetts Institute of Technology measured its value indirectly by performing ground-state hyperfine spectroscopy with a hydrogen maser in a magnetic field. This experiment measured the ratio of the magnetic moments of the proton and the electron. The results, combined with theoretical corrections and two additional independent measurements, enabled the calculation of the proton magnetic moment with a precision of about 10 parts in a billion.

In an attempt to surpass the record, the collaboration of scientists from Mainz University, the Max Planck Institute for Nuclear Physics in Heidelberg, GSI Darmstadt and the Japanese RIKEN institute applied the so-called double Penning trap technique to a single proton for the first time (see figure 1). One Penning trap – called the analysis trap – is used for the non-destructive detection of the spin state, through the continuous Stern-Gerlach effect. In this elegant approach, a strong magnetic inhomogeneity is superimposed on the trap, so coupling the particle's spin-magnetic-moment to its axial oscillation frequency in the trap. By measuring the axial frequency, the spin quantum state of the trapped particle can be determined. And by recording the quantum-jump rate as a function of a spin-flip drive frequency, the spin precession frequency ν_L is obtained. Together with a measurement of the cyclotron frequency ν_c of the trapped particle, the magnetic moment

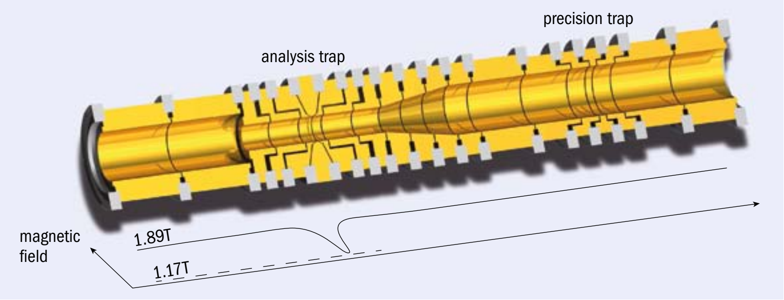


Fig. 1. The double Penning trap set-up used to measure the proton magnetic moment with an unprecedented precision of 3.3 parts in a billion. (Image credit: Georg Schneider.)

of the proton μ_p is obtained finally in units of the nuclear magneton, $\mu_p/\mu_N = \nu_L/\nu_c$.

This approach has already been applied with great success in measurements of the magnetic moments of the electron and the positron. However, the magnetic moment of the proton is about 660 times smaller than that of the electron, so the proton measurement requires an apparatus that is orders of magnitude more sensitive. To detect the proton's spin state, the collaboration used an extremely strong magnetic inhomogeneity of 300,000 T/m^2. However, this limits the experimental precision in the frequency measurements to the parts-per-million (ppm) level. Therefore a second trap – the precision trap – was added about 45 mm away from the strong magnetic-field inhomogeneity. In this trap the magnetic field is about 75,000 times more homogeneous than in the analysis trap.

To determine the magnetic moment of the proton, the first step was to identify the spin state of the single particle in the analysis trap. Afterwards the particle was transported to the precision trap, where the cyclotron frequency was measured and a spin flip induced. Subsequently the particle was transported back to the analysis trap and the spin state was analysed again. By repeating this procedure several hundred times, the magnetic moment was measured in the homogeneous magnetic field of the precision trap. The result, extracted from the normalized resonance curve (figure 2), is the value $\mu_p = 2.792847350(9)\mu_N$, with a relative precision of 3.3 ppb.

In the BASE experiment at the AD the

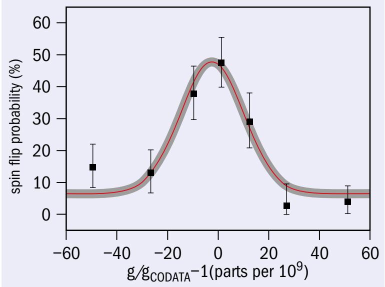


Fig. 2. The measured g value normalized to the currently accepted value g_{CODATA}. The solid line is a maximum-likelihood fit to the data, avoiding the need for data binning. The shaded area indicates the 1σ confidence band. Binned data points with 1σ error bars are shown for visualization and do not enter the line fit explicitly. It took about four months to record the entire set of 450 data points. (Image credit: Andreas Mooser.)

technique will be applied directly to a single trapped antiproton and will potentially improve the currently accepted value of the magnetic moment by at least a factor of 1000. This will constitute a stringent test with baryons of CPT symmetry – the most fundamental symmetry underlying the quantum field theories of the Standard Model of particle physics. CPT invariance implies the exact equality of the properties of matter–antimatter conjugates and any measured difference could contribute to understanding the striking imbalance of matter and antimatter observed on cosmological scales.

Further reading

A Mooser *et al.* 2014 *Nature* **509** 596.

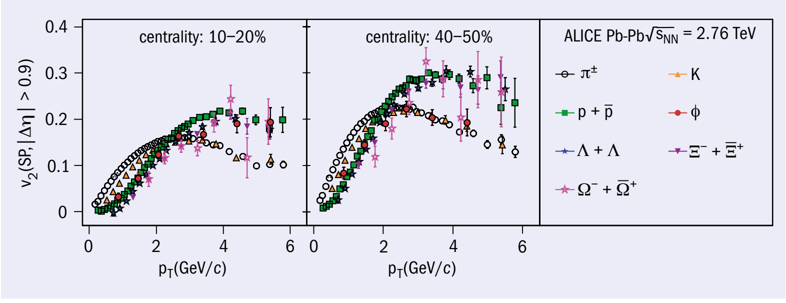
LHC PHYSICS

ALICE and the flowing particle zoo

Relativistic heavy-ion collisions produce large numbers of particles that do not move individually, but rather as an organized group, with a collective motion known as flow. Flow studies at Brookhaven's Relativistic Heavy-Ion Collider (RHIC) contributed to the surprising realization that the hot and dense matter created in the collisions behaves like a perfect liquid and not as a hadron gas. Now, the ALICE collaboration at the LHC has looked further into how these effects vary for different particle species.

In relativistic heavy-ion collisions the collective motion, or flow, is governed by the spatial anisotropy of the almond-shaped overlap region of the colliding nuclei and the initial density inhomogeneities of the fireball. These features are transformed, through interactions between the produced particles, into an anisotropy in momentum space. The degree of this transformation depends on the ratio of shear viscosity to entropy, η/s, which quantifies the friction of the created matter. This resulting anisotropy in particle production can be quantified by a Fourier analysis of the azimuthal distribution relative to the system's symmetry plane, characterized by Fourier coefficients, v_n. The second harmonic, v_2, is known as the elliptic-flow coefficient.

One of the major outcomes from RHIC was the measurement of the elliptic flow of identified particles. These results led to the conclusion that the matter created acts as a system where the value of η/s is very close to the lower bound of ħ/4πkB conjectured within anti-de Sitter/conformal field theory – i.e. a nearly perfect liquid. At low values of transverse momentum (p_T), for $p_T < 2$ GeV/c, the experiments found an interesting mass-ordering of $v_2(p_T)$, attributed to the interplay between elliptic and radial flow.



The p_T-differential v_2 for different particle species, represented by the different symbols and colours, for the 10–20% (left plot) and the 40–50% (middle plot) centrality intervals of PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

Radial flow tends to create a depletion in the particle p_T spectrum at low values, which increases with increasing particle mass and transverse velocity. When introduced in a system that exhibits azimuthal anisotropy, this depletion becomes larger along the shorter axis of the anisotropy, thereby reducing v_2. The net result is that at a fixed value of p_T, heavier particles have a smaller value of v_2 than lighter ones. In the intermediate p_T region ($2 < p_T < 5$ GeV/c), the v_2 of baryons is larger than that of mesons. This phenomenon was conjectured to originate within a picture where flow develops at the partonic level and quarks coalesce into hadrons during hadronization. The proposed mechanism was argued to lead to the observed hierarchy in the flow values – the so-called number of constituent quarks (NCQ) scaling.

The ALICE collaboration, profiting from the unique particle-identification capabilities that the detector set-up provides, had measured v_2 in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for different centrality intervals and various particles: π, K, p, Λ, Ξ^-, Ω^- (and their antiparticles), K^0_s and ϕ. The figure illustrates how v_2 develops for different particle species within the same centrality interval in central (left plot) and peripheral (middle plot) PbPb collisions.

A clear mass ordering is seen for all centralities in the low-p_T region (i.e. $p_T \leq 2$ GeV/c). Comparisons with hydrodynamic calculations in this transverse-momentum range indicate that the produced matter at the LHC seems to favour a value of η/s smaller than twice the quantum mechanical limit. In the intermediate p_T region ($p_T > 2$ GeV/c), although the particles tend to group according to their type (i.e. mesons and baryons), the NCQ scaling, if any, is only approximate. In particular, the ϕ-meson, with a mass close to that of p and Λ, seems to follow the baryon band in central events and shifts progressively to the band of mesons for peripheral collisions. This seems to indicate that the mass, rather than the number of constituent quarks, is the driving force of the v_2 evolution with p_T also in the intermediate region.

Further reading

B B Abelev *et al.* (ALICE Collaboration) 2014 arXiv:1405.4632 [nucl-ex].

Higgs and top: a new window on dark matter

With the discovery of a Higgs boson at the LHC two years ago, the last piece of the Standard Model puzzle fell into place. Yet, several mysteries remain, one of which is the enigma of the origin of dark matter. One of the most popular classes of models predicts that the dark matter is made of weakly interacting neutral and colourless particles, χ, with mass ranging from a few to a few hundred giga-electron-volts. The LHC, with its high-energy collisions, provides an excellent pace to search for such particles, and the CMS collaboration has been taking a new look at ways in which they could be produced.

Until recently, the main experimental method to look for dark-matter particles was to exploit their elastic scattering on nuclei inside sensitive detectors, working typically at low temperatures. These direct-detection experiments aim to observe the scattering by measuring the momentum of the recoiling nucleus. While interesting hints for dark-matter detection in various mass ranges have been reported by some of these experiments, none of these hints ▷

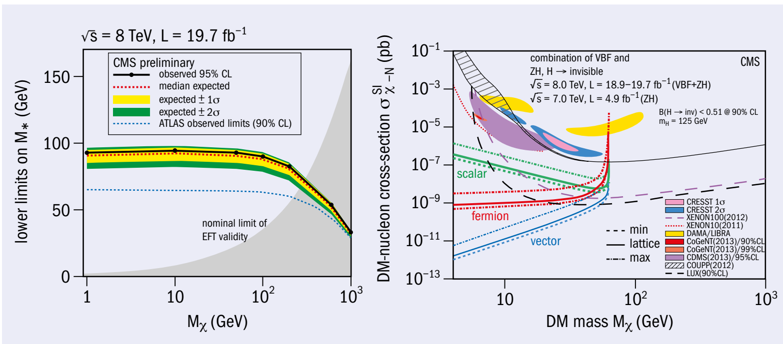


Fig. 1. Left: Limits on the dark-matter particle mass as a function of the effective interaction scale from the associated production of the particle with a top-quark pair. Fig. 2. Right: The limits set on the dark-matter particle mass from the search for invisible Higgs-boson decays compared with those from direct-detection experiments.

have been confirmed by later, more precise measurements.

Several years ago, a new idea appeared: to look for the production of pairs of dark-matter particles in high-energy particle collisions, like those at the LHC, via a process described by the same Feynman diagram as the scattering of the dark-matter particles on quarks inside the nuclei, but "rotated" by 90°. While such direct-detection experiments look for the process $q_\chi \rightarrow q_\chi$, experiments at the LHC can look for $q\bar{q} \rightarrow \chi\chi$. The challenge is to trigger on these events, because dark-matter particles would leave no trace in the detector. One possibility is to search for a more complicated process, where an additional particle, for example a gluon or a photon, is produced together with the dark matter.

The CMS experiment has performed a number of such searches, which are referred to collectively as mono-X searches, because they look for a single object, X, recoiling against the invisible particles. Recently, these searches have been extended to more complicated signatures, for example the production of dark matter in association with a pair of top quarks, which are produced in abundance at the LHC. The new analysis looks for top-quark pairs that are recoiling against a large amount of "missing" transverse momentum, carried away by dark-matter particles.

As figure 1 shows, a new measurement by CMS of the production of top-quark pairs in association with missing transverse momentum sets stringent limits in the plane of the dark-matter particle mass M_χ vs an effective interaction energy scale, M^* (CMS Collaboration 2014a). The interaction of dark matter with the known particles is usually assumed to be carried by new "messenger" particles. If the messengers are heavy – which would be a good reason why they have not yet been seen – the interaction can be approximated via a point-like interaction with an effective energy scale of M*. This is similar to Enrico Fermi's effective theory of muon decay, where the messenger – a W boson – is much heavier than the muon.

Another interesting way to look for dark matter is based on precision measurements of the properties of the Higgs boson. If the mass of the dark-matter particle is less than roughly half of the Higgs boson mass, for instance, $M_\chi < 60$ GeV, then it is possible to look for a direct decay of the Higgs boson into a $\chi\chi$ pair. This decay is called "invisible" because its products are not detected.

The CMS collaboration recently published a search for such invisible Higgs-boson decays, where the production of the Higgs is tagged either by the presence of a Z boson (associated ZH production), or by the presence of two forward jets, characteristic of vector-boson fusion (CMS Collaboration 2014b). The upper limits set on the invisible branching fraction of the Higgs boson are 51% and 58% at a 90% and 95% confidence level, respectively. The former limit can be translated to limits on the mass of the dark-matter particle vs its interaction cross-section with a nucleon, which allows for a direct comparison with the limits coming from various direct-detection experiments, as figure 2 shows. The limits are set for various types of dark-matter particle: scalar, vector, or a Majorana fermion. They are significantly more stringent than the direct-detection limits for low masses for dark matter, emphasizing the complementarity of the searches by the LHC and the direct-detection experiments.

Further reading

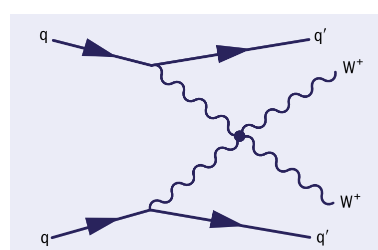
CMS Collaboration 2014a PAS B2G-13-004: https://cds.cern.ch/record/1697173?ln=en.
CMS Collaboration 2014b submitted to *EPJC*, arXiv:1404.1344.

ATLAS finds evidence for the rare electroweak W±W± production

ATLAS EXPERIMENT

The Standard Model of particle physics has been extremely successful in predicting a vast variety of phenomena – so successful, that it is easy to forget that some of its predictions have not yet been verified. A very important one, related intimately to electroweak symmetry breaking, is that the gauge bosons (γ, W and Z) can interact with each other through quartic interactions. Four such interactions are allowed in the Standard Model: WWWW, WWZZ, WWZγ and WWγγ. The other boson combinations are forbidden on symmetry grounds. Now the ATLAS collaboration has found evidence for a process involving the first of these three – the WWWW interaction.

The WWWW and WWZZ interactions, in particular, are of great theoretical interest. If there were no Higgs boson, the rate of these processes would become unphysically large. With the discovery of a Higgs boson, they have remained interesting as a way to study electroweak symmetry breaking and even to probe for new heavier Higgs bosons. At the LHC, the WWWW interactions can be studied through the radiation of W bosons from quarks (see figure). This is a rare process, making the interaction of W bosons particularly rare and difficult to detect.



Representative Feynman diagram for the WWWW quartic-gauge interaction at the LHC.

The ATLAS collaboration has presented the first evidence of this rare process involving a quartic WWWW interaction in a paper submitted to *Physical Review Letters*. The ATLAS analysis selected events with two same-charge W bosons (reconstructed through their leptonic decays to electron or muon and their respective (anti)neutrinos) and two jets. The background from other Standard Model processes is reduced by using the fact that these processes rarely produce two leptons with the same electric charge, together with the knowledge that the quarks that recoil off the radiated W bosons will produce jets that are separated widely and have a particularly large invariant mass.

Data collected by the ATLAS experiment show an excess of these events across the predicted background, with a statistical significance of 3.6σ. The measured fiducial cross-section is 1.3±0.4 fb, in agreement with the Standard Model expectation of 0.95±0.06 fb, and provides the first step into a previously untouched segment of the Standard Model.

Further reading

ATLAS Collaboration 2014 submitted to *Phys. Rev. Lett.* arXiv:1405.6241.

CONFERENCE

New results from ATLAS at Quark Matter 2014

At the Quark Matter 2014 conference, held in Darmstadt on 19–25 May, ATLAS presented a variety of new results based on lead–lead (PbPb) and proton–lead (pPb) data collected during Run 1 of the LHC. The PbPb results included new measurements of event-by-event correlations and fluctuations of collective flow, high-statistics measurements of photon and W production, and studies of jet quenching using charged particles, single jets, nearby jet pairs and jet-fragmentation functions. The results from pPb data included precision measurements of long-range pseudorapidity correlation and associated azimuthal structures, and high-p_T production of charged particles, Z bosons and jets. Here are some of the highlights.

Following the first observation of highly asymmetric dijets in PbPb collisions, the study of jet quenching has been an essential part of the heavy-ion physics programme at the LHC. Measurements of the production of electroweak bosons provide important control data for the study of jet quenching, as well as for investigating nuclear modifications to parton distribution functions. ATLAS presented new results on the measurement of W-boson production via the electron and muon decay modes in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, with yields of W bosons obtained as a function of centrality and pseudorapidity. A good agreement was found between the two decay channels. The yields are in agreement with the predictions based on modified next-to-leading-order calculations, while leading-order calculations underestimate the yield.

Jets produced in heavy-ion collisions can interact with the medium that is produced in the collisions and lose energy through the phenomenon of jet quenching. This energy loss suppresses the rate of jets produced in these collisions, relative to proton–proton collisions, where no such effects are present. Using the high-statistics proton–proton data set from 2013 as the new reference, ATLAS presented the most precise measurement of jet suppression to date. In central collisions, the jet yields are suppressed by more than a factor of two below a jet transverse momentum, p_T, of around 150 GeV (see figure 1), but the suppression is found to be reduced at higher p_T.

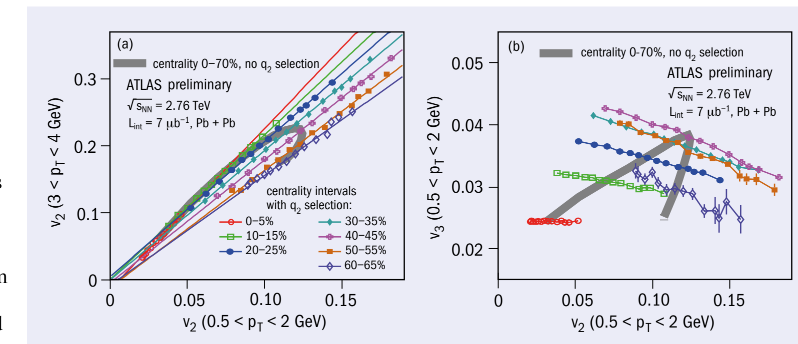


Fig. 2. Correlation of (a) v_2 in two different p_T ranges, and (b) v_3 and v_2 in the same p_T range. The data points in each centrality interval correspond to the 14 event classes with different ellipticity selected via an event-shape engineering technique. The data are overlaid with the centrality dependence without event-shape selection (thick line).

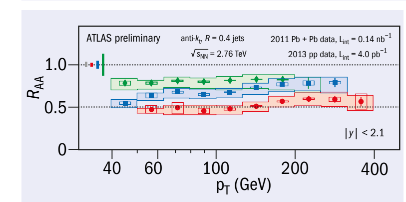
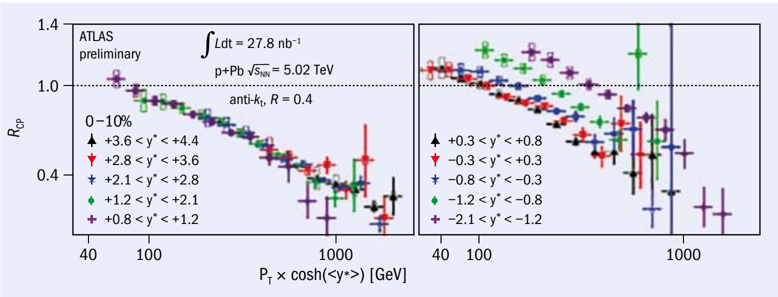
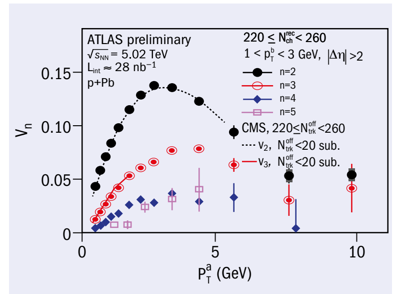


Fig. 1. The modification of jet yields, quantified by the nuclear modification factor, R_{AA}, as a function of jet p_T for three centrality bins: 0–10% (red circles), 30–40% (blue squares) and 60–80% (green diamonds).

ATLAS presented first results on direct correlations between the elliptic flow coefficient, v_2, and higher-order flow harmonics, v_3, v_4 and v_5, in PbPb collisions. This correlation is obtained via an event-shape engineering technique, in which events within the same centrality interval are divided into different classes according to the observed ellipticity in the forward pseudorapidity. The correlation in v_2 for two different ranges in p_T (figure 2(a)) shows non-trivial centrality dependence but is linear within a narrow centrality interval. This linearity indicates that viscous effects are controlled by the size of the system, and not its overall shape. The v_3–v_2 correlations, shown in figure 2(b), reveal a surprising anticorrelation between the ellipticity and triangularity of the initial geometry, which is not accessible via the traditional measurements. The v_4–v_2 and v_5–v_2 correlations provide the most direct and detailed picture of the interplay between the linear and nonlinear collective dynamics in the final state of the PbPb collisions.

Turning to the pPb runs, the large data sample collected at $\sqrt{s_{NN}} = 5.02$ TeV in 2013 allowed ATLAS to measure the jet production over the widest kinematic range ever probed in proton–nucleus collisions. ▷





Left: Fig. 3. The modification of jet yields in 0–10% central pPb collisions relative to 60–90% peripheral pPb collisions, quantified by the nuclear modification factor R_{CP}. Jets are reconstructed by an anti-kT algorithm with R = 0.4 and plotted as a function of $p_T\cosh(y^*)$, which reflects the Bjorken x in the proton (left) and nucleus (right) of the hard-scattering process. Vertical error bars represent the statistical uncertainty, while the boxes represent the systematic uncertainties. Right: Fig. 4. The azimuthal harmonics of the ridge, $v_2(p_T)$, $v_3(p_T)$ $v_4(p_T)$ and $v_5(p_T)$, obtained for $|\Delta\eta| > 2$ and the reference p_T range of 1–3 GeV. The error bars and shaded boxes represent the statistical and systematic uncertainties, respectively. Results in $220 \le N_{ch}^{rec} < 260$ are compared with the CMS data obtained by subtracting the peripheral events (the number of offline tracks $N_{trk}^{off} < 20$), shown by the solid and dashed lines.

This measurement has the potential to reveal how the hard partonic content inside matter is modified deep inside the high-density nucleus, and explores the interplay between hard processes and collision geometry – a major topic at the conference. When considering collisions of all impact parameters, the rate of jets was found to be slightly above what would be expected just from the proton's collisions with individual nucleons in the lead nucleus. This slight excess is generally consistent with models of the modified parton densities in nuclei. However, when pPb collisions are selected by "centrality", unexpected effects appear (figure 3). The rate of jets is suppressed strongly in apparently central events (with small impact parameter) and enhanced in those that appear peripheral (large impact parameter). Furthermore, the modifications of the jet rate have a striking pattern as a function of the energy and rapidity, implying that the modifications might originate in the proton, rather than the nuclear, wave function.

Using the same pPb data set, ATLAS also performed a detailed study of the long-range pseudorapidity correlation and its azimuthal structure, as characterized by the first five Fourier harmonics, v_1–v_5. The study extended the previous measurements at the LHC of v_2 and v_3 to higher p_T and events with higher charged-particle multiplicities. Moreover, the measurements of v_1, v_4 and v_5 were presented in this context for the first time. As figure 4 shows, the p_T dependences of v_n are found to be similar to PbPb collisions with comparable multiplicities, suggesting that the collective flow – the main attribute of the dense system created in PbPb collisions – might also be present in pPb interactions.

● **Further reading**
For the full list of results presented by ATLAS at Quark Matter 2014, see https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults.

Policy

US particle-physics community sets research priorities

In May, an advisory panel to federal funding agencies in the US approved a proposed plan for the future of the country's particle physics. Top priorities in the plan – written by the Particle Physics Prioritization Panel (P5) – include continuing to play a major role at the LHC in Europe; building a world-leading neutrino programme hosted in the US; and participating in the development of a proposed future linear collider, if a decision is made in Japan to go forward with construction.

The P5 report culminates a process open to all members of the US particle-physics community that lasted more than a year. It was presented to the High Energy Physics Advisory Panel (HEPAP), a body that formally advises the US Department of Energy Office of Science and the National Science Foundation.

The plan recommends a US particle-physics programme that will pursue research related to the Higgs boson, neutrinos, dark matter, dark energy and inflation, and as-yet-undiscovered particles, interactions and physical principles. It advises increasing investment in the construction of new experimental facilities.

The P5 panel envisions the US as the host of an international programme of neutrino research that will operate the world's most powerful neutrino beam and, with international partners, build a major long-baseline neutrino facility complemented by multiple small, short-baseline neutrino experiments. Launching this programme will involve a change in direction, because the panel recommends reformulating the currently planned Long-Baseline Neutrino Experiment as an internationally designed, co-ordinated and funded programme called the Long-Baseline Neutrino Facility, or LBNF. The facility would use a neutrino beam at Fermilab, upgraded through the proposed project called the Proton Improvement Plan II, together with a massive liquid-argon neutrino detector placed underground, probably at the Sanford Underground Research Facility in South Dakota, and a smaller detector placed nearer to the source of the beam.

The plan emphasizes the need for the US to begin several planned second-generation dark-matter experiments immediately, with a vision to build at least one large, third-generation experiment in the US near the beginning of the next decade. It also recommends increasing funding for the particle-physics components of cosmic surveys.

Society

OECD report praises innovation at CERN

In early June, the Organisation for Economic Co-operation and Development (OECD) published their Global Science Forum (GSF) report, "The Impacts of Large Research Infrastructures on Economic Innovation and on Society: Case studies at CERN". The report praises the culture of innovation at CERN, and finds that the laboratory has "evident links to economic, political, educational and social advances of the past half-century".

Through in-depth, confidential interviews with the people involved directly, the report focuses on two of CERN's projects: the development of superconducting dipole magnets for the LHC and the organization's contribution to hadron therapy.

As many as 1232 superconducting dipoles – each 14 m long and weighing 35 tonnes – steer the particle beams in the LHC. Following the R&D phase in the years 1985–2001, a call to tender was issued for the series production of the dipoles. R&D had included building a proof-of-concept prototype, meeting the considerable challenge of designing superconducting cables made of niobium-titanium (NbTi), and designing a complex cryostat system to keep the magnets cold enough to operate under superconducting conditions (*CERN Courier* October 2006 p28).

The report notes that although innovation at the cutting edge of technology is "inherently difficult, costly, time consuming and risky", CERN mitigated those risks by keeping direct responsibility, decision-making and control for the project. While almost all of the "intellectual added value" from the project stemmed from CERN, contractors interviewed for the study reported their experience with the organization to be positive. CERN's flexibility and ability to innovate attracts creative, ambitious individuals, such that "success breeds success in innovation", note the report's authors.

The second case study covered CERN's contribution to hadron therapy using beams of protons, or heavier nuclei such as carbon, to kill tumours. The authors attribute CERN's success in pushing through medical research to its relatively "flat" hierarchy, where students and junior members of staff can share ideas freely with heads of department or management. A key project was the three-year Proton Ion Medical Machine Study, which started in 1996 and submitted a complete accelerator-system design in 1999 (*CERN Courier* October 1998 p20). CERN's involvement in hadron therapy is also a story of collaboration – the laboratory retains close links with CNAO, the National Centre for Oncological Hadron Therapy in Italy, and the MedAustron centre in Austria and others (*CERN Courier* December 2011 p37).

The report also praises the longevity of CERN, which allows it to "recyle" its infrastructure for new projects, and the CERN staff. This manpower is described as a "great asset" for the organization, which can be deployed in response to strategic "top down" decisions or in response to initiatives that arise in a "bottom up" mode.

● For the full report, see www.oecd.org/sti/sci-tech/CERN-case-studies.pdf.

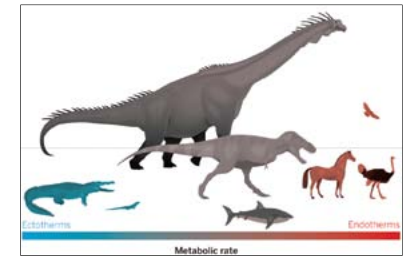
Sciencewatch

Compiled by John Swain, Northeastern University

Dinosaurs: neither hot nor cold

There has been much debate whether dinosaurs were cold-blooded ectotherms, like modern reptiles, or warm-blooded endotherms, like most modern mammals. However, they might have been neither, according to the bold suggestion that has been put forward by John Grady of the University of New Mexico and colleagues.

By plotting (in a mass-independent manner) growth rate as a function of metabolic rate for nearly 400 living and extinct animals (using known scaling laws and annual bone rings to obtain dinosaur growth rates), the researchers find that dinosaurs lie in-between the exotherms and endotherms. They wpropose that dinosaurs were likely to have been what they call mesotherms – a class of animal that can raise its body temperature, but does not maintain it at a specific level. This would have allowed the dinosaurs to outcompete sluggish exotherms, and crowd out the large-animal niches, preventing endotherms from becoming bigger and ruling the Earth – at least until an asteroid hit. Modern mesotherms are few, but include tuna and the echidna.



Dinosaurs and some living animals are mesotherms, raising but not maintaining their body temperature. (Image credit: adapted from Grady et al.*/Illustration Greg Harris.)*

● **Further reading**
J M Grady *et al.* 2014 *Science* **344** 1268.

Life, but not as we know it

The genetic code of all natural organisms is expressed in terms of the pairs A-T and G-C – the letters representing pairs of complementary bases in DNA that code for the 20 amino acids from which all proteins are made. Now, Denis Malyshev of the Scripps Research Institute and colleagues have persuaded living bacteria to accept a third pair: d5SICS and dNAM – call them X and Y. Both the DNA and RNA can hold the extra X-Y pairs and the bacteria – if provided with X and Y, which they cannot synthesize themselves (they would die outside the lab environment) – can reproduce with the new code. The new letters do not code for anything yet, but this allows, in principle, for 172 amino acids, and vastly increases the variety of proteins that could be produced. The work could also help to shed light on why the bases used by the life we know are what they are.

● **Further reading**
D A Malyshev *et al.* 2014 *Nature* **509** 385.

Plant mimicry

Mimicry is common in the animal world, but Ernesto Gianoli and Fernando Carrasco-Urra of the Universidad de Concepción have found that the woody climbing vine *Boquila trifoliolata*, which grows in the temperate South American rainforest, can vary nine features of its leaves, including size, shape, and colour. This allows it to mimic any of 12 other species – possibly to help it avoid herbivores. A single plant can even change the shape of its leaves as the vine moves between species on which it climbs. Mimicry in plants, or "crypsis", has been seen before, but only via taking on an appearance that is similar to a background or colour pattern, or looking like one single plant, so this is a record.

● **Further reading**
E Gianoli *et al.* 2014 *Current Biology* **24** 984.

Self-repairing plastic

Self-repair is common in living organisms, but is now also possible in plastics. S R White of the University of Illinois at Urbana-Champaign and colleagues have developed plastics with biomimetic vascular networks of capillaries filled with two liquids. These materials, when punctured, allow the liquids to ooze out, mixing to form a gel that plugs the hole and later polymerizes into a robust filler, repairing the damage. Holes more than 35 mm in diameter fill within 20 minutes, with mechanical function restored within 3 hours with 62% of the original material performance.

● **Further reading**
S R White *et al.* 2014 *Science* **344** 620.

The quantum eye

Folk wisdom has it that the eye is sensitive around the single-photon level, but so far all studies have been done with sources with classical photon statistics, such as lamps, LEDs, lasers, etc. It is therefore interesting to see what does actually happen with single photons. Leonid Krivistky of the Data Storage Institute of the Agency for Science Technology and Research in Singapore and colleagues used spontaneous parametric down-conversion of 266-nm Nd:YAG laser pulses to generate photon pairs, directing one to a retinal rod cell from a *Xenopus laevis* toad, while using the other as a trigger. Without the need for the statistical modelling used in previous studies, they find solid proof of single-photon sensitivity, with a quantum efficiency of 29±4.7%. This is close to estimates for human rod cells obtained earlier from behavioural experiments.

● **Further reading**
N M Phan *et al.* 2014 *Phys. Rev. Lett.* **112** 213601.

Did Ötzi come from Sardinia?

An analysis of the genome of Ötzi, the 5300 year-old Tyrolean "iceman", has yielded interesting insights into the origins of the well-preserved mummy found near the Austrian–Italian border in 1991. Martin Sikora of Stanford University and colleagues have found that his Y-chromosome lineage is one found almost only in Corsica and Sardinia, and is rare elsewhere in Europe.

Using in addition genomic data from modern Sardinians and ancient Europeans from other geographic regions, the team also suggests that the Ötzi's Sardinian ancestry is shared with individuals associated with the beginning of agriculture during the Neolithic period, and the transition away from hunter-gatherer life in Europe.

● **Further reading**
M Sikora *et al.* 2014 *PLOS Genetics* 10 e1004353.

Astrowatch

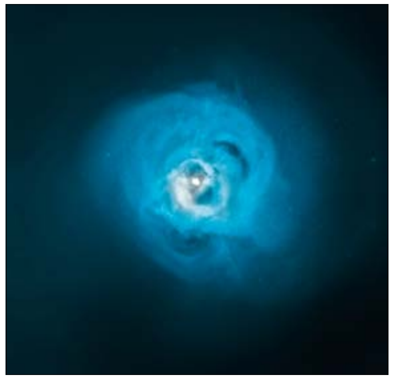
Compiled by Marc Türler, ISDC and Observatory of the University of Geneva, and University of Zurich

Do X-rays reveal a sterile neutrino?

A detailed study of galaxy clusters using NASA's Chandra X-ray Observatory and ESA's XMM-Newton has found a mysterious X-ray signal. One intriguing possibility is that the X-rays are produced by the decay of sterile neutrinos – a candidate particle for dark matter – although there is doubt that this is the correct interpretation.

The mystery surrounds an unidentified X-ray emission line at energy $E = 3.56 \pm 0.03$ keV, found in the Perseus galaxy cluster, during a study of data from both the Chandra and XMM-Newton missions led by Esra Bulbul from the Harvard-Smithsonian Center for Astrophysics. The team also found the line in a combined study of 73 other galaxy clusters observed with XMM-Newton. As these clusters have different redshifts, this finding excludes, a priori, the possibility that the line is an instrumental artifact. The authors of the study admit, however, that the detection is at the limit of the current instrumental capabilities.

The researchers argue that there should be no atomic transitions in thermal plasma at this energy. They therefore suggest that this emission line could be a signature from the decay of a sterile neutrino with a mass of $m_s = 2E = 7.1$ keV. Sterile neutrinos are a hypothetical type of neutrino predicted to interact with normal matter via gravity only. They have been put forward as candidates to explain dark matter, at least partially.



A new study of the Perseus galaxy cluster, shown in this image, and others using Chandra and XMM-Newton, has revealed a mysterious X-ray signal in the data, which might be from sterile neutrino decay. (Image credit: Chandra: NASA/CXC/SAO/E.Bulbul et al.; XMM-Newton: ESA.)

The paper on these findings was submitted to *The Astrophysical Journal* in February and posted on the arXiv preprint server, igniting a flurry of activity, with 60 new papers having cited this work in the four months from March to June. Some of these papers explore the sterile neutrino interpretation, while others suggest that other types of candidate dark-matter particles, such as axions, might have been detected.

What makes many researchers doubt the results, is that the intensity of the emission line is significantly different from one cluster to the other. While the detection in the full sample of clusters corresponds to a mixing angle for the decay that is below previously determined upper limits, the line in Perseus is much brighter than expected for this mixing angle (based on the cluster's mass and distance), deviating significantly from other subsamples. The fact that the detected signal is very weak (with an equivalent width in the full sample of about 1 eV only) and located within 50–110 eV of several known faint lines is also suspicious. However, the authors recognize that "the dark matter explanation is a long shot" and that they "have a lot of work to do before they can claim, with any confidence, that they have found sterile neutrinos".

This study on a possible dark-matter signal follows the report on the excess of gamma-ray emission from the Galactic Centre observed with Fermi, which strengthened the case for a signal from annihilating dark matter (*CERN Courier* April 2014 p13). In this case, it is still early days. Have the researchers stumbled on something really interesting? Future studies and better instrumentation are needed to settle the issue.

Further reading

E Bulbul *et al.* 2014 *ApJ* **789** 13.

Picture of the month

This colorful image of the Whirlpool Galaxy is a composite of X-ray observations (in purple) from the Chandra X-ray Observatory superimposed on the optical image from the Hubble Space Telescope. With more than 10 days of overall observing time, Chandra revealed about 500 X-ray sources in this beautiful spiral galaxy, also known as Messier 51 (*CERN Courier* July/August 2010 p14). Most of these sources are X-ray binaries consisting of pairs of objects where a compact star, either a neutron star or a black hole, is capturing material from an orbiting companion star. The infalling material is accelerated by the intense gravitational field of the compact star and heated to millions of degrees, producing a luminous X-ray source. The more diffuse, or fuzzy, X-ray emission in this interacting galaxy comes from gas that has been heated to multi-million degrees by supernova explosions of massive stars. (Image credit: X-ray: NASA/CXC/Wesleyan Univ./R Kilgard *et al.*; optical: NASA/STScI.)

CERN Courier Archive: 1971

A look back to CERN Courier vol. 11, August 1971, compiled by Peggie Rimmer

CERN II

Heisenberg's principles

Remote from the noise and bustle of Europe's capital cities, in the charming German lakeside town of Lindau close to the borders of Austria and Switzerland, Nobel prize winners in physics gathered from June 28–July 2 to talk of their science and its interaction with society.

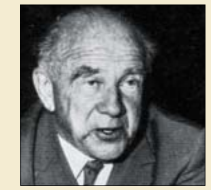
The first of these annual meetings of Nobel prize winners was a medical congress in 1951. This year's assembly was 21st in the series and seventh where the main theme was physics.

Readers of the *CERN Courier* would have been particularly interested in the conference given by Professor Heisenberg in which he analysed his past and present attitudes to the Super Proton Synchrotron project [for a 300 GeV machine, approved in February 1971 to be built in a new laboratory adjacent to CERN Lab I]. He was reputed at one time to be strongly opposed to the project, the eminence grise in German science discouraging participation. Certainly in a number of interviews he made clear his reservations about the early proposals, but reports on his views were sometimes tendentious and even, one suspects, apocryphal. Here was an opportunity to hear how Heisenberg's thoughts had evolved and what new considerations led to his approbation.

Among the points he raised was the fact that when projects of the size and significance of the 300 GeV machine are in question, it is naïve to believe that politics can be ignored. The scale of expenditure, choice of location and relevant urgency are all matters where public discussion is necessary and public policy, i.e. politics, is involved.

First the physics

From the physics angle, previous experience would suggest that larger machines – higher energies – would yield new information and new knowledge. Moreover, the field of elementary particle physics concerns physics at its most fundamental, the laws of nature to which all physical laws can be reduced. At the same time, the technological stimulus created by this work at the frontiers of knowledge is of general importance. Such arguments certainly were in favour of the construction of a machine of 100 GeV or so, but for still higher energies



Werner Heisenberg: thoughts on big machines.

the question of cost and relative value had to enter into consideration.

There was a question mark too over the type of discoveries that can be made at higher energies. It could be that there is no longer subdivision of matter, but only the creation of new particles or new particle states. Cosmic ray evidence had not suggested that there was anything more fundamental to be found.

In any case, the ISR should reveal any basically new phenomena and if conventional machines of higher energy were then shown to be necessary, one should first consider new techniques so that they could be built more cheaply.

Competing claims

At the level of expenditure, sums need to be diverted from other activities and if a new synchrotron is built collectively this is also a drain on the national pools of assets. Choices of this nature are disagreeable – particularly when trying to balance the quest for fundamental knowledge against day-to-day problems. National defence raises even more difficulties; money forthcoming from that direction must be made available by those responsible for the defence.

The UK made a positive contribution towards resolving this argument by agreeing to participate in the new CERN programme at the expense of their national effort – even if it were to mean closing a national laboratory. It is rare to see demands on the State purse accompanied by proposals that require sacrifices by those making the demand.

Dispassionate advice

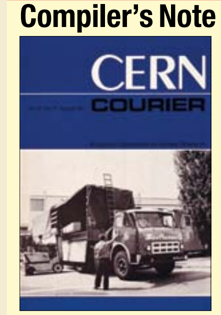
One acute problem facing governments was their dependence on scientists for advice. In a field as restricted as high-energy physics, the advisers are inevitably interested parties and a sacrifice is necessary as a proof of good faith, to convince the politicians of the genuineness of their submissions. The UK physicists had done so.

Undoubtedly, the formation of an international community is to be encouraged and its institutions and centres supported. Happily, CERN is one of the best examples of international collaboration but several others, such as Trieste, Ispra, Grenoble and the various space centres are all contributing.

The question of the location of these centres is, however, also important, and a reasonable distribution across Europe is indispensable. It had been hoped that the German site of Drensteinfurt would be selected for the 300 GeV machine but the cost reductions associated with the proposition for CERN Lab II shifted the balance in favour of this second choice. The stability afforded to the present laboratory was also a valuable element and insured against a future over-provision of facilities in this domain and consequently an excessive production of physicists. Taking all these aspects into consideration, the compromise solution of CERN Lab II is a good one.

● Compiled from texts on pp221–222.

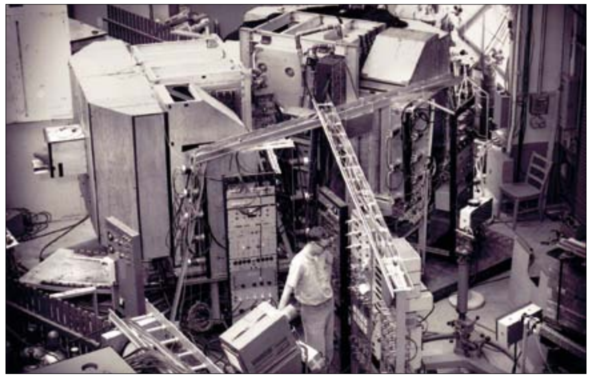
Compiler's Note



Werner Heisenberg died some four months before John Adams announced to the June 1976 Council meeting that the Super Proton Synchrotron (SPS) had accelerated protons to 300 GeV. Adams there and then sought and obtained Council's approval to increase the energy to 400 GeV. Five minutes later, he reported that 400 GeV protons were circulating in the machine. Contrary to Heisenberg's supposition, the Intersecting Storage Rings (ISR) did not make any major physics breakthroughs, but did launch CERN's outstanding hadron-collider programme, which is approaching a zenith as the LHC prepares to deliver 13 TeV proton–proton collisions, with the indefatigable SPS as the final accelerator in the pre-injection chain.

CP violation's early days

A brief look back at a discovery that surprised the world of particle physics 50 years ago.



The experiment that discovered CP violation at Brookhaven was set up in a neutral beamline, directed inside the ring of the Alternating Gradient Synchrotron. Visible here are the two spectrometer magnets positioned at 22° to the beam. Spark chambers tracked particles before and after the magnets. (Image credit: Brookhaven National Laboratory.)

In the summer of 1964, at the International Conference on High-Energy Physics (ICHEP) in Dubna, Jim Cronin presented the results of an experiment studying neutral kaons at Brookhaven National Laboratory. In particular, it had shown that the long-lived neutral kaon can decay into two pions, which implied the violation of CP symmetry – a discovery that took the physics community by surprise. The news was greeted with some scepticism and met a barrage of questions. Everyone wanted to be satisfied that nothing had been overlooked, and that all other possibilities had been considered carefully and ruled out. People need not have worried. Cronin, together with Val Fitch, visiting French physicist René Turlay and graduate student Jim Christenson, had spent months asking themselves the same questions, testing and cross-checking their results thoroughly. There was, in the end, only one conclusion that they could draw from their observations: CP symmetry was not a perfect symmetry of nature. Only when the researchers were completely satisfied did they make their findings known to the physics community. It is testament to their patience and the quality of their work that the result was so robust to scrutiny. It was 15 years later that Cronin and Fitch received the 1980 Nobel Prize in Physics for the discovery.

The announcement of a broken symmetry was not new to the physics community, having first occurred only a few years previously, when the maximal non-conservation of parity (P) in the weak interaction was discovered by Chien-Shiung Wu and her colleagues in 1957, following the proposal by Tsung-Dao Lee and Chen-Ning Yang that parity violation might explain puzzles in the decays of charged kaons. The disturbing conclusion that the laws of physics depend on the frame of reference was evaded, however, because experiments soon showed that symmetry under charge-conjugation (C) was also maximally violated. Therefore, as long as the combined operation, CP, was a good symmetry, the possibility of an absolute distinction between left-handed and right-handed co-ordinate systems would be prevented, being compensated exactly by the asymmetry between particles and antiparticles. CP invariance had already been suggested as the means to restore symmetry conservation by Lev Landau, and by Lee and Yang, so the situation seemed to be resolved neatly.

When the news came in 1964 that CP was also a broken symmetry, it was harder to accept, because no elegant alternative was available to replace CP invariance. There was also the issue of the treasured CPT theorem: if CPT holds, then CP violation implies violation of time-reversal (T) symmetry. The discovery of CP violation led to the unsettling conclusion that the microscopic laws of physics do indeed allow absolute distinctions between left- and right-handed co-ordinate systems, between particles and antiparticles, and between time running forwards and backwards.

By the early 1960s, the neutral kaon system had already proved to be a rich testing ground for new physics. Its "strange" behaviour had been a matter for scrutiny since its discovery in cosmic rays in 1946. Neutral kaons were found to be produced copiously through the strong interaction, while their long lifetimes suggested decays via the weak interaction. In 1953, Murray Gell-Mann assigned the K^0 a "strangeness" quantum number, $S = 1$, which was conserved by the strong force but not by the weak force. This implied that there must exist a distinct anti-K^0, $\overline{K}^0$, with $S = -1$. However, because both the K^0 and $\overline{K}^0$ appeared to decay to two pions, the distinction between the particles was blurred somewhat. The situation prompted Gell-Mann and Abraham Pais to propose, in 1955, that the states of definite mass and lifetime, labelled K_1 and K_2, were instead an admixture of the two particles, and were even and odd, respectively, under the CP transformation. Under the assumption of CP invariance, the K_2 was forbidden to decay to two pions. This gave it a much longer lifetime than the K_1, as observed.

The primary motivation for the experiment at Brookhaven was to study a phenomenon peculiar to the kaon system called regeneration (see box, p22). Fitch, an expert on kaons, had approached Cronin, who with Christenson and Turlay had built a state-of-the-art spectrometer based on spark chambers, which could be operated with an electronic trigger to select rare events. It was just what was needed for further tests of regeneration. Finding a "new upper limit" for K_2 decaying to 2π was a secondary consideration, listed ▷

under "other results to be obtained". The experiment was approved for 200 hours of run-time, and about half of this was devoted to the "CP invariance run", across five days towards the end of June 1963. Turlay began the analysis of the CP run in the autumn. By the time it was complete, early in 1964, it was clear that 2π decays were present, with 45±10 events, corresponding to about one in 500 of K_2 decays to charged modes. In the conclusion of their seminal paper, published in July 1964, the team stated: "The presence of a two-pion decay mode implies that the K_2 meson is not a pure eigenstate of CP" (Christenson *et al.* 1964).

During the year that followed, there was feverish activity in both the experimental and theoretical communities. The discovery of CP violation raised many questions about its origins, and the size of the effect. In particular, it was unclear from experiment whether the effect was occurring in the kaon decays (direct CP violation) or in neutral kaon mixing (indirect CP violation). Indeed, the results could be explained solely by invoking indirect CP violation, which was achieved by the simple, but ad hoc, addition of a small admixture of the CP = +1 eigenstate to the mass eigenstate of the long-lived neutral kaon. This was parameterized by the small complex parameter ε, which had a magnitude of about 2×10^{-3}. The two states of distinct (short and long) lifetime were then $K_S = K_1 + \varepsilon K_2$ and $K_L = K_2 + \varepsilon K_1$ (to order ε^2).

Among the many theoretical papers that followed in the wake of the discovery of CP violation was that by Lincoln Wolfenstein in August 1964, which proposed the "superweak" model. This was the minimal model, which accounted for the observed effect by adding a single CP-violating contribution to the $\Delta S = 2$ mixing-matrix element between the K^0 and the $\overline{K^0}$. There was no CP-violating contribution to the kaon decays themselves, hence the model offered a prediction that the phenomenon would be seen only as a feature of neutral kaon mixing. Alternatively, a "milliweak" theory would include direct CP-violating contributions to neutral kaon decays ($\Delta S = 1$), as well as to the kaon mixing-matrix element. Another proposal was that the action of an all-pervading long-range vector field of cosmological origin could cause the observed decay to 2π without invoking CP violation. This was a relatively easy option to test experimentally, because it predicted that the decay rate would depend on the energy of the kaons.

The experimental confirmation of the $\pi^+\pi^-$ decay of the long-lived kaon came early in 1965, from groups at the Rutherford Laboratory in the UK and at CERN. These experiments also dispensed swiftly with the vector-field proposal. There was no evidence for the variation of the decay rate with energy. Experiments were now needed to determine the CP-violating parameters η_{+-} and η_{00} – the ratios of the amplitudes for the K_L and K_S decays into $\pi^+\pi^-$ or $\pi^0\pi^0$, respectively (see box p24) – the measurable quantities being the related magnitudes ($|\eta_{+-}|$, $|\eta_{00}|$) and phases (ϕ_{+-}, ϕ_{00}).

In 1964, Jack Steinberger had realized that the interference between K_S and K_L decaying to the same final state ($\pi^+\pi^-$) could provide a valuable way to study CP violation. Results published in 1966 from two such experiments at CERN's Proton Synchrotron provided measurements of $|\eta_{+-}|$ and ϕ_{+-}. The more difficult challenge of measuring decays to $\pi^0\pi^0$ was taken up by spark-chamber experiments at CERN, Brookhaven and Berkeley. In another experiment at CERN, a beam of K_L passed along a pipe through the Heavy-Liquid Bubble Chamber (HLBC), in which the photons from the π^0 decays would convert. First results from the spark-chamber experiments seemed to indicate that $|\eta_{00}|$ was much larger than $|\eta_{+-}|$. However, in late 1968 the HLBC collaboration presented a result that was compatible with $|\eta_{00}| = |\eta_{+-}|$. After some confusion, the spark-chamber experiments confirmed this result and also measured ϕ_{00}.

More refined experiments were to follow, giving more precise measurements for the different decay modes. By the time of the 13th ICHEP in London in 1974 – 10 years after the announcement in Dubna – all results agreed perfectly with the predictions of the superweak model, with no need for direct CP violation. However, a new theory that accounted for CP violation was already in the air – and with it new challenges for a new generation of experiments.

Neutral kaon mixing, oscillations and regeneration

Because the weak interaction does not conserve strangeness, second-order weak-interaction processes mediate transitions between the strangeness eigenstates K^0 and $\overline{K^0}$. Therefore, the physical particles (eigenstates of mass and lifetime) are linear combinations of K^0 and $\overline{K^0}$, and states born as one or the other "oscillate" between these two eigenstates before decaying. The two physical eigenstates are called K_S and K_L – short and long – reflecting their different lifetimes. Allowed to propagate for long enough, a mixed beam of neutral kaons will evolve into a pure beam of K_L. Because K^0 and $\overline{K^0}$ have different interactions with matter, if an initially pure K_L beam enters matter, the $\overline{K^0}$ component will interact preferentially, forming a different admixture of K^0 and $\overline{K^0}$. This admixture must be different from the pure K_L that entered the matter, which means that a component of K_S is "regenerated" in the beam. Regeneration is not an effect of CP violation, but it is used extensively in "regenerators" in kaon experiments.

Further reading

J H Christenson *et al.* 1964 *Phys. Rev. Lett.* **13** 138.
J W Cronin 1993 Nishina Memorial Lecture.

Résumé
Les débuts de la violation de CP

À l'été 1964, les résultats d'une expérience étudiant les kaons neutres au laboratoire Brookhaven ont pris par surprise la communauté de la physique des particules. En particulier, cette expérience avait montré que le kaon neutre à durée de vie longue peut se désintégrer en deux pions, ce qui implique la violation de la symétrie de CP, donc une subtile différence entre les particules et les antiparticules. Cette découverte a soulevé de nombreuses questions concernant l'origine et la dimension de ce phénomène. Des expériences plus affinées ont suivi, donnant des mesures plus précises pour les différents modes de désintégration. L'article retrace brièvement ce qui a suivi au cours de la décennie suivante, jusqu'à l'été 1974.

Theresa Harrison, University of Warwick. With thanks to Donald Cundy and Italo Mannelli.

The NA48 experiment at CERN's Super Proton Synchrotron, which followed NA31 in the 1990s. From right to left: the target for the production the K_S beam (in the blue frame) followed by the multicoloured final collimator; the almost 120-m-long evacuated decay tube; the liquid krypton calorimeter – new for NA48 and key to detecting the decays to neutral pions. (Image credits, right to left: CERN-EX-9610003-07, CERN-EX-9610003-05, CERN-EX-9610003-04.)

NA31/48: the pursuit of direct CP violation

Over two decades, two experiments at CERN proved the existence of a subtle difference between particles and antiparticles.

In 1973 – almost 10 years after the surprising discovery of CP violation – Makoto Kobayashi and Toshihide Maskawa produced the first theory of the phenomenon in the context of the Standard Model. They proposed a bold generalization of a mechanism that Sheldon Glashow, John Iliopoulos and Luciano Maiani had put forward in 1970. The "GIM mechanism" suppressed strangeness-changing weak neutral currents through the introduction of a fourth quark – charm – and was, in turn, an extension of ideas that began with Nicola Cabibbo (*CERN Courier* September 2013 p53). Kobayashi and Maskawa introduced a third generation of quarks (b and t), and a full 3×3 unitary matrix parameterizing complex couplings between the quark-mass eigenstates and the charged weak gauge bosons ($W^{\pm}$). In this model, a single complex phase in the matrix accounted for all observed CP-violating effects in the kaon system, and provided for CP violation in matrix elements, both for mixing and for decays – that is, for both indirect and direct CP violation.

The discovery of the b quark in 1977 brought the theory of Kobayashi and Maskawa well and truly into the spotlight, and the hunt began to search for the predicted CP violation in the b-quark system (p26). In kaon physics, the crucial experimental question now was to disprove the superweak model for CP violation (p22), which had no need for direct CP violation. In contrast, in the Kobayashi-Maskawa model, the parameter describing direct CP violation, ε', was nonzero. However, considerable theoretical uncertainty remained concerning its value, which was potentially too small to be measured by the existing experimental techniques. This provided fresh impetus to the search for direct CP violation, and prompted renewed efforts at CERN and at Fermilab to meet the experimental challenges involved.

At CERN, the NA31 experiment was proposed in 1982 with the explicit goal of establishing whether the ratio ε'/ε was nonzero. This required measuring all four decay rates of K_S and K_L to the charged and neutral 2π final states (see box, p24). The concept behind NA31 was to measure K_S and K_L decays at the same locations (binned in momentum) to provide essentially the same acceptance for each set of events, and so reduce the dependence on Monte Carlo simulation. The experiment employed a mobile K_S target, able to move along a 50-m track, with data-taking stations every 1.2 m. Additionally, beam and detector fluctuations were limited by rapidly alternating the data-taking between K_S and K_L. The experimental limitations were determined by statistics and background suppression. In both cases, a liquid argon calorimeter was used to achieve the stable, high-quality energy and position resolution that was crucial for reconstructing the $\pi^0\pi^0$ decays. The calorimeter was developed by exploiting the expertise acquired by the group of Bill Willis at CERN with the first liquid-argon calorimeter at the Intersecting Storage Rings.

In 1988, NA31 found the first evidence for direct CP violation, with a result that was about three standard deviations from zero. However, shortly after this the E731 experiment at Fermilab reported a measurement that was consistent with zero. These conflicting results increased the importance of answering the question on the existence of direct CP violation, and prompted the design of a new generation of detectors, both at CERN (NA48) and at Fermilab (KTeV). ▷

60 years of CERN

Members of NA31 – many of whom also took part in NA48 – gathered at CERN to celebrate the award of the 2005 EPS High-Energy Particle Physics Prize for having shown, for the first time, direct CP violation in the decays of neutral kaons. (Image credit: CERN-GE-0510038-01.)

The NA48 experiment was designed to handle a 10-fold increase in beam intensity and event rates compared with NA31. It incorporated a magnetic spectrometer to reduce background in the charged-pion mode and a new calorimeter to replace the liquid-argon original. The novel liquid-krypton calorimeter was fully longitudinally integrating, and had fine granularity in two dimensions to provide faster detection with superior resolution for neutral-pion decays. Systematic effects were also greatly reduced in NA48 by observing all four decay modes concurrently.

In 1999, both the KTeV and NA48 experiments were successful in measuring direct CP violation in the decay of neutral kaons, clearly establishing that CP violation was not just confined to kaon mixing (*CERN Courier* September 1999 p32). The discovery was later recognized by honours in both Europe and the US. In 2005, the European Physical Society's High-Energy Physics Prize was awarded jointly to CERN's Heinrich Wahl, for his "outstanding leadership of challenging experiments on CP violation", and to the NA31 collaboration as a whole, for having shown, for the first time, direct CP violation in the decays of neutral K mesons. Wahl, who was spokesman of NA31, had a long association with CP-violation experiments since his arrival at CERN in 1969, and was also a major proponent of NA48. Two years later, Italo Mannelli, Wahl and Bruce Winstein, leader of the KTeV collaboration, were awarded the W K H Panofsky prize of the American Physical Society, in recognition of their "leadership in the series of experiments that resulted in a multitude of precision measurements of properties of neutral K mesons, most notably the discovery of direct CP violation".

During the past 50 years, the study of the neutral-kaon system has gone hand-in-hand with the development of the Standard Model. In particular, CP violation in neutral kaons provided the experimental stimulus for Kobayashi and Maskawa to propose the third generation of quarks. That boosted the motivation to search for direct CP violation, which in turn motivated improvements in experimental techniques. The search for direct CP violation across several generations of experiments led to the tantalizing hint of a result in NA31, before the effect was eventually nailed down by KTeV and NA48.

Victor Hugo wrote in *Les Misérables*: "La symétrie, c'est l'ennui". A less succinct but more poetic sentiment was expressed by Wolfenstein at the conference on CP violation at Chateau de Blois in 1989, which celebrated the 25th anniversary of the discovery of the unexpected effect. He described broken symmetry as "something more intriguing and perhaps more beautiful than perfect symmetry". Another 25 years on, that sentiment is stronger than ever.

Measuring direct CP violation in the neutral-kaon system

CP violation in general manifests itself as a difference between the behaviours of particles and antiparticles (apart from the obvious charge inversion). In the original experiment at Brookhaven, the observation of the decay of a K_L to two pions could be explained by one effect or by a combination of two effects:

- The K_L is an exact eigenstate of CP with eigenvalue –1. Its decay is mediated by an interaction that violates CP, allowing it to decay to a CP = +1 final state (e.g. two pions). Such direct CP violation is parameterized by a complex quantity, ε'.
- The K_L eigenstate is an admixture of CP = –1 and CP = +1 components, the CP = +1 part being a (complex) fraction ε of the total. This is the case if the mixing amplitude (which causes transitions between K^0 and $\overline{K}^0$) violates CP. This is called indirect CP violation.

The parameter ε measures the admixture of the CP = +1 eigenstate in the K_L mass eigenstate, so if this were the only source of CP violation, the fraction of K_L decays with a two-pion final state normalized to K_s would be independent of whether the two pions were $\pi^+\pi^-$ or a $\pi^0\pi^0$. Any observed difference between the amplitude ratios η_{+-} and η_{00} would be evidence for direct CP violation, and the deviation from unity of their squared-ratio (which depends on the respective event rates) can be shown to be six times the real part of ε'/ε. This is given experimentally by the ratio-of-ratios of event rates. Therefore, to make a measurement of the direct CP violation parameter, the four rates must be measured. Because ε'/ε is of the order of 10^{-3}, the measurements are particularly difficult.

Résumé

NA31/NA48 : à la recherche de la violation de CP directe

En 1973, Makoto Kobayashi et Toshihide Maskawa produisaient la première théorie de la violation de CP dans le contexte du Modèle standard. Avec une troisième génération de quarks, ce modèle prévoyait une violation de CP aussi bien dans le mélange de kaons neutres (violation de CP indirecte) que dans leurs désintégrations (violation de CP directe). Cette avancée a incité à redoubler d'efforts dans la recherche de la violation de CP directe, encore jamais observée alors. Au CERN, l'expérience NA31 a trouvé la première trace de ce phénomène en 1988. Dix ans plus tard, NA48, l'expérience qui a pris la suite de NA31, établissait clairement la violation directe de CP dans les kaons neutres, ce qui devait conduire à l'attribution de prix internationaux aux physiciens qui ont travaillé sur ces deux expériences.

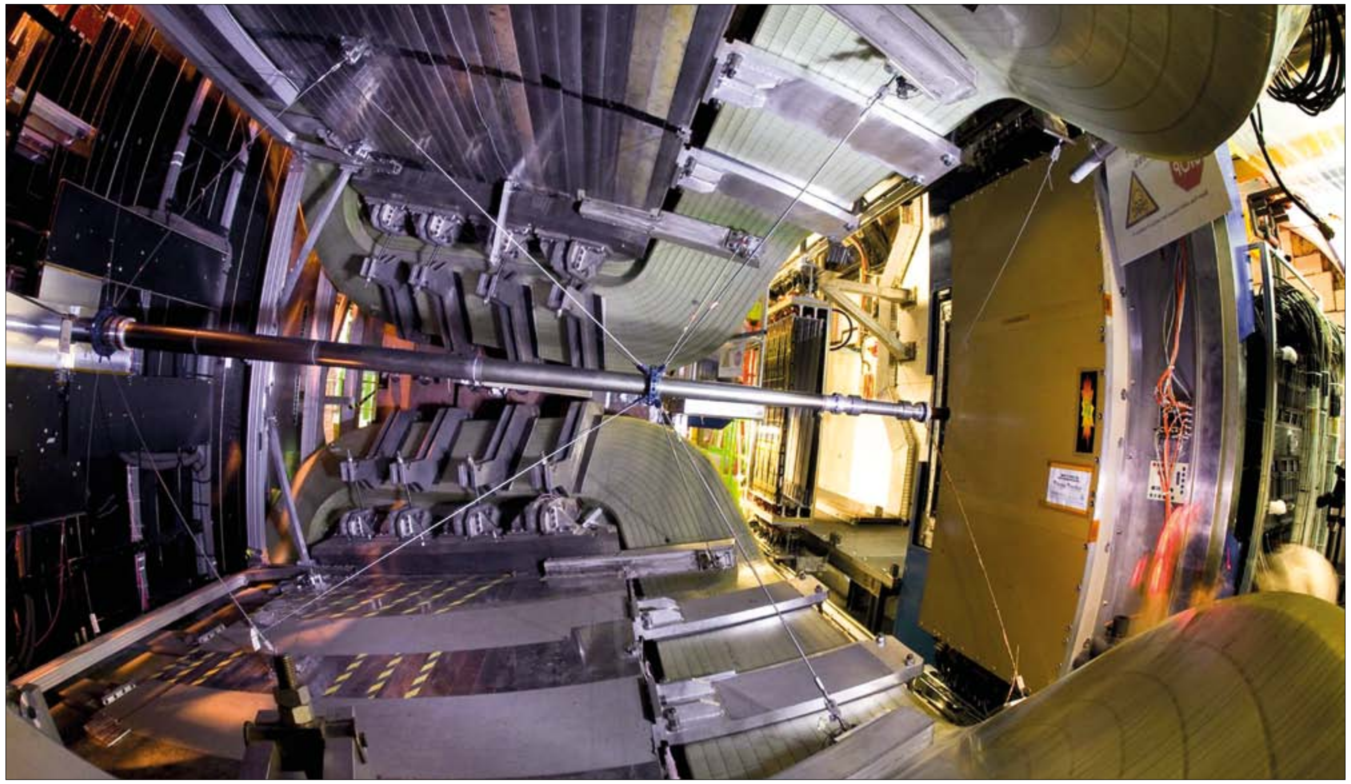
Theresa Harrison, University of Warwick. With thanks to Donald Cundy and Italo Mannelli.

CERN Courier July/August 2014

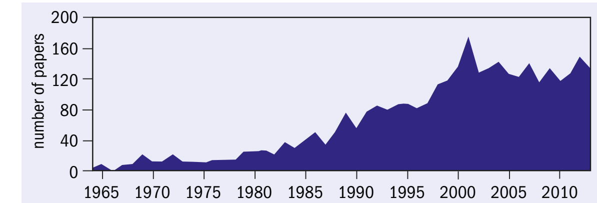
Flavour physics

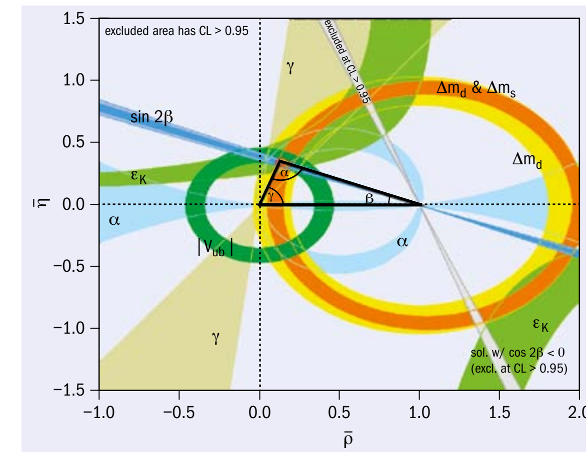
What's next for CP violation?

Fifty years after the discovery of CP violation, interest in differences between the behaviour of matter and antimatter shows no sign of abating.



The LHC provides a copious source of b hadrons, which the LHCb experiment, in particular, is designed to exploit. Here, the beam pipe is seen passing through the experiment's dipole magnet. (Image credit: CERN-PHOTO-0807022 – 01.)





Top: Fig. 1. Growth of interest in CP violation from discovery to modern day, as measured by journal paper titles containing "CP violation" or "CP invariance" (from INSPIRE records by publication year). Above: Fig. 2. Constraints on the parameters of the CKM unitarity triangle, as compiled by the CKMfitter group (http://ckmfitter.in2p3.fr/).

The observation of CP violation was first revealed to an unsuspecting physics community in July 1964 (p21). Since then, as figure 1 shows, interest in this puzzling phenomenon has grown significantly. So what is driving this interest and what remains to be studied?

One reason that the field remains so vibrant is the connection with the existence of our matter-dominated universe. As Andrei Sakharov showed in 1967, the absolute distinction between matter and antimatter provided by C and CP violation is – together with baryon number violation and a period of thermal inequilibrium – one of the necessary conditions to generate a net baryon asymmetry from an initially symmetrical state (Sakharov 1967). Moreover, because the Standard Model provides only a small amount of CP violation, and also constrains strongly the amount of baryon number violation and the phase transitions that cause inequilibrium, it cannot account for the amount of matter surviving the almost total annihilation that must have occurred in the early universe. This mystery strikes a chord among scientists and the general public alike, because it points to a way to search for physics beyond the Standard Model and hints at a connection to one of the biggest questions in science: why is there something rather than nothing?

Although answers to such grandiose questions are by their nature elusive, there has been significant progress in understanding CP violation during the past 50 years, and there are excellent prospects for further advances. Perhaps the two most important experimental results in the field, since the discovery, occurred around the turn of the millenium, corresponding to the peak in figure 1. The first was the long-sought observation of direct CP violation through the measurement of a nonzero value of the parameter $\mathrm{Re}(\varepsilon'/\varepsilon_K)$ of the neutral kaon system (see p23). The second was the discovery of CP violation in the B system.

The model introduced by Makoto Kobayashi and Toshihide Maskawa predicted that CP-violation effects should occur also in the B sector (Kobayashi and Maskawa 1973). Specifically, as Ikaros Bigi, Ashton Carter and Tony Sanda showed, a potentially large asymmetry could be expected between the decay rates of B^0 and $\overline{B}{}^0$ mesons to the $J/\psi\, K_S$ final state, as a function of time after production (Carter and Sanda 1981, Bigi and Sanda 1981).

To make the observation, however, would require much larger numbers of B mesons than had been produced in previous experiments. Moreover, it would be necessary to have a precise measurement of the decay time, together with knowledge of the flavour of the B meson at production – that is, "flavour tagging". To meet these challenges, several different designs were put forward, with the preferred solution being a high-luminosity asymmetrical e^+e^- collider, with a detector equipped with a silicon vertex detector and particle-identification capability. By colliding electrons and positrons at the centre-of-mass energy of the ϒ(4S) meson, the facilities could exploit the resonant production of quantum entangled B–$\overline{B}$ meson pairs, while the decay vertices of the two particles could be separated owing to the beam-energy asymmetry. Two such "B factories" were built – the PEP-II and KEKB accelerators, with their associated detectors BaBar and Belle, at SLAC in California and KEK in Japan, respectively. In 2001, the first results from the two experiments were enough to establish that CP is indeed violated in the B system (*CERN Courier* April 2001 p5).

By the time that the research programmes at the B factories had been completed, the accelerators had broken records for the highest instantaneous and integrated luminosities of any particle collider, allowing the measurement of the CP-violation parameter in $B^0 \to J/\psi\, K_S$ decays to be improved to a precision of better than 3%. This parameter is referred to as $\sin(2\beta)$, because it is sensitive to the angle β of the Cabibbo-Kobayashi-Maskawa (CKM) unitarity triangle, which represents in the complex plane the relation $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$ between elements of the CKM quark-mixing matrix. Other measurements of the properties (angles and sides) of this triangle are all consistent, as figure 2 shows, where the constraints all overlap at the apex of the triangle. This astonishing agreement between data and theory led to the award of the 2008 Nobel Prize in Physics to Kobayashi and Maskawa.

The data represented in figure 2 are the result of enormous effort from experimentalists and theorists alike. Indeed, because the properties of quarks can be studied only through final states containing hadrons, detailed knowledge of the properties of the strong interaction specific to each interaction is necessary to obtain quantitative information about CP violation. In a few "golden modes", such as the measurement of $\sin(2\beta)$, the associated uncertainties are negligible. But for others such as ε_K, input from, for example, lattice QCD calculations, is essential.

The large samples of B mesons available at BaBar and Belle allowed several further milestones in CP-violation studies to be achieved. One notable result is the observation of direct CP violation in $B^0 \to K\pi$ decays (*CERN Courier* September 2004 p5). Further advances have become possible more recently because an even more copious source of b hadrons has become available – the LHC at CERN. In particular, the LHCb experiment is designed to exploit the potential for heavy-flavour physics at the LHC by instrumenting the forward region of proton–proton collisions, and therefore optimizing the acceptance of the b quark–antiquark pairs produced.

As with BaBar and Belle, LHCb is equipped with excellent vertexing and particle-identification capabilities. An additional challenge for an experiment at a hadron collider is the efficient rejection of minimum-bias events that occur at a high rate. This is achieved in LHCb by exploiting signatures of the decay products of heavy flavoured particles, such as muons with comparatively high transverse momentum and a secondary vertex that is significantly displaced from the proton–proton interaction point. Unlike the B factories, LHCb can study all types of b hadron – a feature ▷

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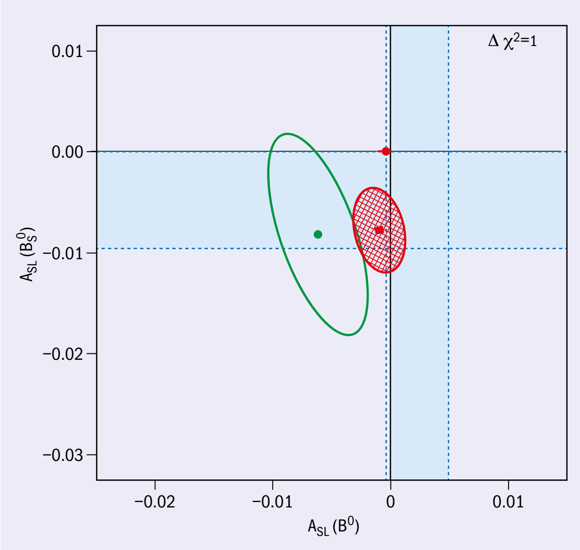

Fig. 3. Constraints on the parameters describing CP violation in B^0–$\overline{B}^0$ and B_s^0–$\overline{B}_s^0$ mixing amplitudes, denoted $A_{SL}(B^0)$ and $A_{SL}(B_s^0)$, from the D0 dimuon measurement (green ellipse) together with world averages of the individual parameters (blue bands) from measurements by BaBar, Belle, D0 and LHCb, and their combination (red filled ellipse). The Standard Model point is indistinguishable from the origin. (Image credit: Heavy Flavour Averaging Group, www.slac.stanford.edu/xorg/hfag/.)

that allowed it to make the first observation of direct CP violation in B_s^0 meson decays (*CERN Courier* June 2013 p7). LHCb has also discovered very large – and rather puzzling – CP-violation effects in decays of B mesons to three particles (pions or kaons) (*CERN Courier* November 2012 p7), which need to be understood with further experimental and theoretical investigations.

Future prospects

What, then, remains for studies of CP violation? One important point is that the measurements shown in figure 2 are, on the whole, not limited by theoretical uncertainties. Because the consistency of the measurements provides strong constraints on theories of physics beyond the Standard Model, there is good motivation to continue to improve them. For example, the measurement of the angle γ achieved by studying CP-violation effects in $B \to DK$ decays has negligible theoretical uncertainty. The current constraint, combining results from BaBar, Belle and LHCb, gives an uncertainty of about ±10°. Reducing this uncertainty by an order of magnitude will either further constrain models that contain new sources of CP violation or, perhaps, reveal the presence of new physics. This is one of the main objectives of the next generation of B-physics experiments: the upgraded SuperKEKB accelerator and Belle2 detector at KEK, and the LHCb upgrade at CERN.

There are several other important CP-violating observables in the B system, where the Standard Model predicts small effects, but new physics could result in much larger values being measured in experiments. One good example is the decay mode $B_s^0 \to J/\psi\,\phi$, which is the B_s^0 sector equivalent of $B^0 \to J/\psi\, K_S$, and probes a parameter labelled β_s. In the Standard Model, β_s is expected to be around 1°, whereas the latest results from LHCb and other experiments limit its value to less than about 4°. Similarly, the parameters describing CP violation in the B^0–$\overline{B}^0$ (and B_s^0–$\overline{B}_s^0$) mixing amplitudes, which are the B-system equivalents of ε_K, are expected to be vanishingly small. This has been a topic of considerable interest during the past few years, because the D0 experiment based at Fermilab's Tevatron reported an anomalous charge asymmetry in events with two same-sign muons (*CERN Courier* July/August 2010 p6). These same-sign muons occur in events where both particles resulting from the hadronization of a b quark–antiquark pair decay semileptonically, but one of them decays only after oscillating into its antipartner. The inclusive asymmetry could, therefore, be caused by CP violation in either or both of the B^0–$\overline{B}^0$ and B_s^0–$\overline{B}_s^0$ mixing amplitudes. However, measurements of the parameters describing CP violation in each of the two amplitudes individually do not reveal any discrepancy with the Standard Model, as figure 3 shows. Improved measurements are needed to resolve the situation and are eagerly anticipated.

Contemporary CP-violation searches are not confined to B mesons. Heavy-flavour experiments are abundant sources of charm hadrons, which can be used to investigate matter–antimatter asymmetries. Indeed, D^0–$\overline{D}^0$ oscillations provide a particularly interesting "laboratory" for such searches, because this is the only system involving up quarks in which phenomena similar to those measured in the K^0–$\overline{K}^0$ and B^0–$\overline{B}^0$ systems can be probed. Within the Standard Model, the CP-violating effects are tiny, which provides a potential opportunity for new physics signatures to appear. The small mixing rates make these measurements extremely challenging, but experiments have now been able to establish the mixing phenomena at a high level of significance (*CERN Courier* November 2012 p7). Consequently, charm-physics experiments are becoming more focused on CP violation, and further progress can be foreseen as the accumulated data samples increase.

Because the top quark does not hadronize, it must be studied in different ways from the lighter heavy quarks. It is also, of course, an excellent tool for probing beyond the Standard Model. Among the many tests of the top sector being performed with the unprecedented samples collected by the ATLAS and CMS experiments are studies of CP violation in both the production and decays of top quarks. The discovery of a Higgs boson also provides the opportunity for ATLAS and CMS to search for CP violation in the Higgs sector, which is absent in the Standard Model.

Indeed, the description of CP violation within the context of the Standard Model is highly restrictive: it appears only among the flavour-changing interactions of the quarks. As a consequence, tests of CP violation in other sectors can be carried out with zero Standard Model background, and are therefore particularly sensitive to new sources of asymmetry. In addition to the examples given above, searches for nonzero electric dipole-moments of fundamental particles such as the electron are sensitive to flavour-conserving CP-violation effects. Owing to the amazingly high precision that is achieved in experiments, the measurements are sensitive to the small effects that are expected to be induced by new physics at the tera-electron-volt scale (Baron *et al.* 2014). As yet, however, there are

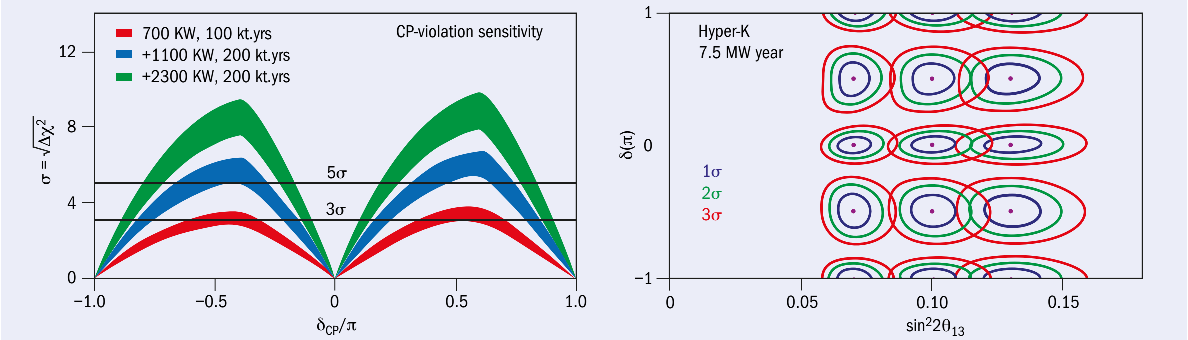

Fig. 4. CP-violation sensitivities of future long-baseline neutrino experiments. Left: Expected sensitivity to reject the hypothesis of no CP violation, as a function of δ_{CP}, for different beam and detection capabilities of LBNF in the US (C Adams et al. *2014 arXiv:1307.7335). Right: Expected contours on the δ_{CP}–$\sin^2 2\theta_{13}$ plane for different true values in Hyper-K in Japan (Hyper-K Working Group 2013 arXiv:1309.0184).*

no hints of a nonzero electric dipole-moment.

Perhaps the best chance of a discovery of a new source of CP violation in the medium-term future is in the lepton sector. Neutrino oscillations can be described by the Pontecorvo-Maki-Nakagawa-Sakata mixing matrix in an analogous way to the CKM matrix of the quark sector. (However, because the leptons do not couple to the strong interaction, the phenomenology of quark and lepton mixing is, in essentially all other respects, completely different.) The recent measurement of a nonzero value of the mixing angle θ_{13} by Daya Bay (*CERN Courier* April 2012 p8) and other experiments shows that all three flavours of neutrino mix with each other to give the physical eigenstates, which is a prerequisite for CP violation to be observable.

The parameter that describes CP violation in neutrino mixing, δ_{CP}, can be measured by comparing the probabilities for electron (anti)neutrino appearance in a muon (anti)neutrino beam. The MINOS experiment, which detects neutrino beams from Fermilab with a far detector at a baseline of 735 km in the Soudan mine in Minnesota, and the T2K experiment, which uses neutrinos from the Japan Proton Accelerator Complex (J-PARC) and a far detector 295 km away in the Kamioka mine, have already made first steps in this direction. Now the NOvA experiment is also under way in the US, using the upgraded beam at Fermilab with a baseline of 810 km (p30). However, far better sensitivity will be needed. For this reason, new and upgraded experiments have been proposed. These include the Long Baseline Neutrino Facility (p12) in the US and Hyper-Kamkiokande (Hyper-K) in Japan, as well as possible projects in Europe and elsewhere. Example sensitivities to δ_{CP} in these experiments are shown in figure 4. Because the observation of CP violation in the lepton sector would give the possibility to explain the baryon asymmetry of the universe, through a mechanism known as leptogenesis, these projects are among the highest-priority science goals in the international particle-physics community. The construction and operation of such projects might take 20 years, but if CP violation is discovered in the lepton sector, it will be worth the wait.

Nonetheless, no one knows currently in which, if any, of these sectors the new sources of CP violation that must exist will appear first. It is therefore essential to continue to explore on as many fronts as possible. In this regard, it might be that the next big breakthrough in the field comes from the same particle that started the whole field off 50 years ago. Decays of kaons to final states containing a pion and a neutrino–antineutrino pair can provide a theoretically clean measurement of the height of the unitarity triangle, and therefore of the amount of CP violation described by the CKM matrix. Moreover, because these decays are highly suppressed, they are highly sensitive to physics beyond the Standard Model. Within the next few years, the NA62 experiment at CERN and the KOTO experiment at J-PARC will improve significantly on previous measurements of these decays, and might, therefore, start to provide hints of CP violation beyond the Standard Model. Such a discovery would provide fertile ground for investigations for the next 50 years.

Further reading

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Résumé

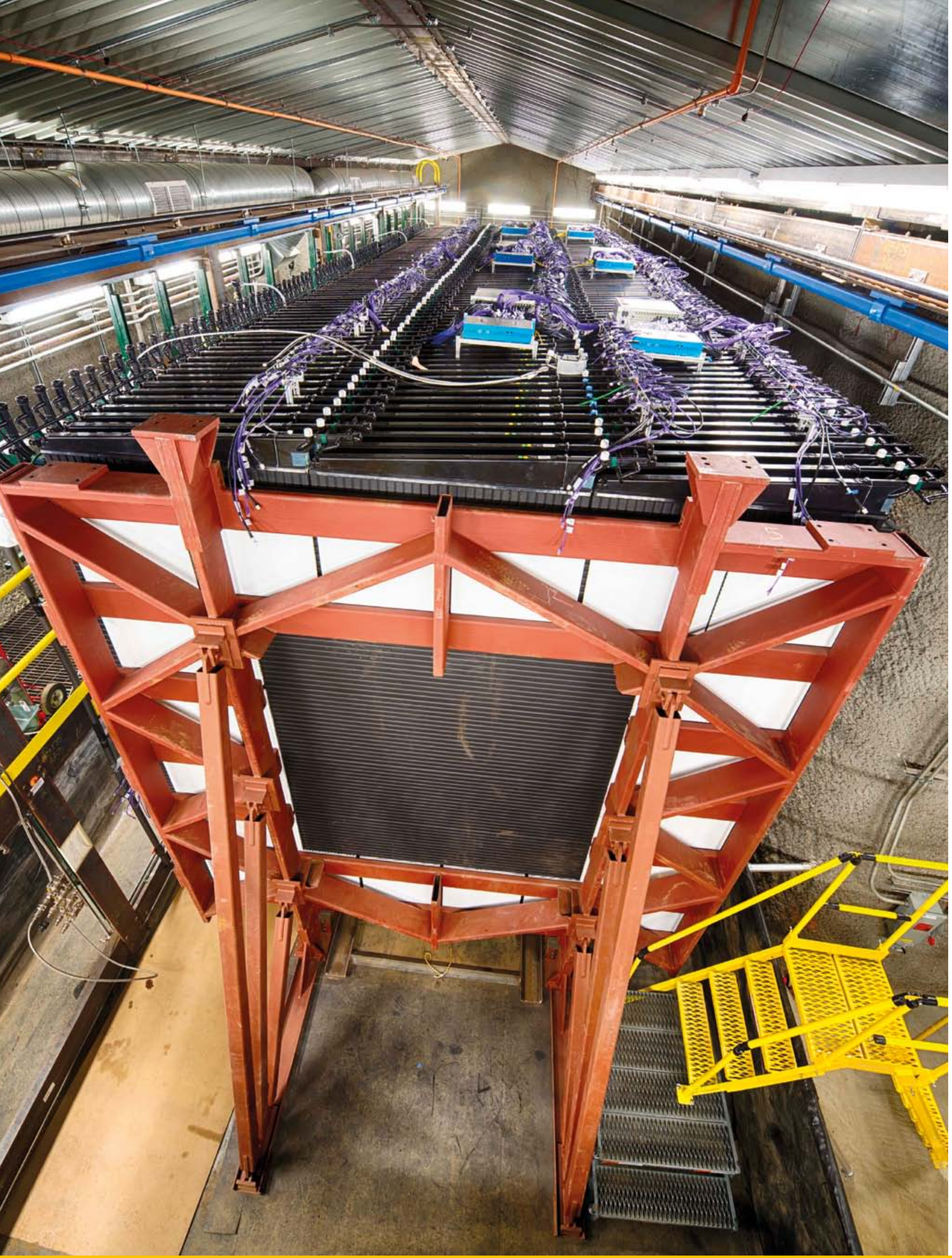
Violation de CP : les perspectives

Cinquante ans après la découverte de la violation de CP, l'intérêt pour les différences entre le comportement de la matière et de l'antimatière reste très vif. En 2001, les expériences ont montré pour la première fois qu'il existe une violation de CP dans les mésons B comme dans les kaons neutres. Depuis lors, un immense travail accompli aussi bien par les expérimentateurs que par les théoriciens a permis de conclure à une concordance remarquable entre les données expérimentales et la théorie de Cabibbo-Kobayashi-Maskawa prédisant le phénomène. Cependant, il existe encore la possibilité de mesures améliorées qui permettraient de fixer des limites à d'éventuelles nouvelles sources de violation de CP, ou, peut-être, de révéler une nouvelle physique.

Tim Gershon, University of Warwick.

NOvA takes a new look at neutrino oscillations

A big detector and a powerful beamline will offer further insight into the masses and mixings of neutrinos.



NOvA, Fermilab's new flagship neutrino-oscillation experiment, has recorded its first neutrinos and is now poised to make precision measurements of electron-neutrino (ν_e) appearance and muon-neutrino (ν_μ) disappearance. These data will help to unravel remaining unknowns in understanding neutrino masses and mixing. In the now standard picture of neutrinos, the three electroweak flavour states (ν_e, ν_μ and ν_τ) are mixtures of the mass eigenstates (ν_1, ν_2 and ν_3) related by a unitary matrix that is parameterized by three mixing angles and a charge-parity (CP) violating phase. Neutrinos are produced and detected in flavour eigenstates but propagate in mass eigenstates. Interference among the mass states means that a neutrino created in a definite flavour state can later be detected in a different flavour state. This oscillation probability is determined by the sizes of the mixing angles, the splittings in the neutrino masses, the energy of the neutrino and the distance it has travelled. Measurements of the oscillation probabilities of neutrinos of known energy that travel a known distance reveal the underlying mass-splittings and mixings.

Thanks to experiments using neutrinos produced in the Sun, in the atmosphere, at particle accelerators and in nuclear reactors, researchers have found out a great deal about neutrino masses and mixing. We know that two neutrinos are relatively close in mass and that the third is relatively far away in mass. We know that the mixing angles are all relatively large, in contrast to mixing angles in the quark sector, which are small. We also know that the two neutrinos that are relatively close in mass contain most of the electron-neutrino flavour, and that the third is a nearly equal combination of muon and tau flavour. However, we do not know if the third mass eigenstate is composed of more ν_μ or ν_τ, or if a new symmetry keeps these two contributions equal. We do not know if neutrinos violate CP symmetry, and we do not know the ordering of the neutrino masses.

Neutrinos could follow a normal hierarchy, with most of the ν_e content contained in the lightest two states, or they could follow an inverted hierarchy with the ν_e content predominantly in the heaviest two states. The neutrino-mass hierarchy is one specific prediction of different grand-unification theories, with implications for cosmological measurements of the absolute scale of neutrino mass. The hierarchy, in combination with results from neutrinoless double-beta decay experiments, plays an important role in determining the Dirac or Majorana nature of the neutrino.

NOvA will use two detectors to measure oscillation probabilities in Fermilab's NuMI (Neutrinos at the Main Injector) muon-neutrino beam. When neutrinos travel the 810 km between Fermilab and Ash River, Minnesota, through the crust of the Earth, scattering of ν_e on atomic electrons can either enhance or suppress the oscillation probability, depending on the mass hierarchy. The effect is ▷

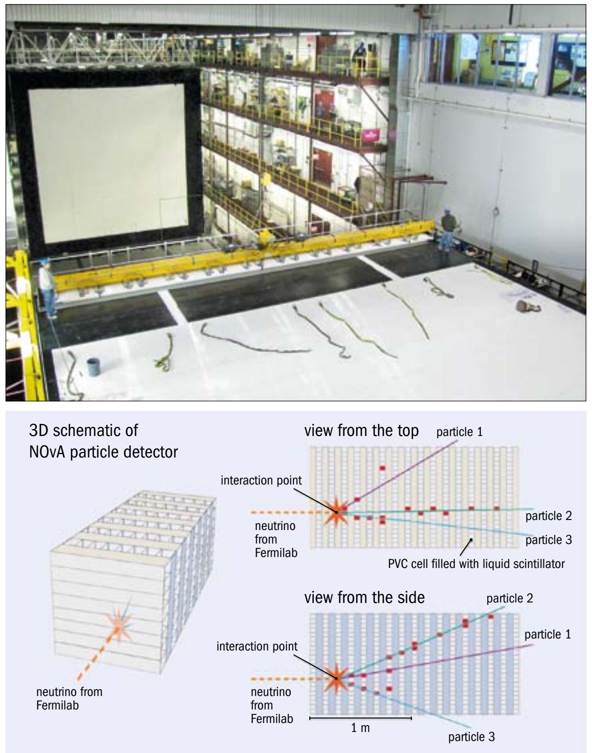


Fig. 2. Top: View of the NOvA far detector as the last module is put into place. Bottom: Schematic of the NOvA detectors. (Image credits: Fermilab Visual Media Services.)

Fig. 1. Photograph of the NOvA near detector, taken from a beam's-eye view. (Image credit: Fermilab Visual Media Services.)

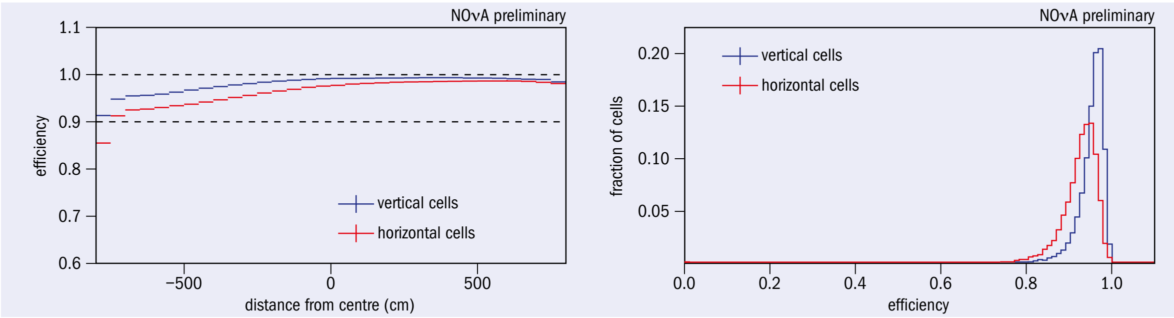


Fig. 3. Left: The efficiency of detecting a minimum-ionizing particle crossing a cell, as a function of the distance from the centre of the cell. Right: A histogram of the detection efficiency at the far end of the cell, made across all of the cells in the detector.

opposite in neutrinos compared with antineutrinos, so by comparing the oscillation probability measured in neutrinos with that measured with antineutrinos, NOvA can determine the mass hierarchy, resolve the nature of ν_3, and begin the study of CP violation in neutrinos.

To achieve these goals, NOvA requires an intense neutrino and antineutrino source. NuMI had routinely delivered 320 kW of beam power to the MINOS and MINERvA experiments during operation of the Tevatron. However, with Tevatron operations now ended, the accelerator complex has been reconfigured to provide twice the beam power to the NuMI beamline (*CERN Courier* October 2013 p6). During a shutdown of a year and a half starting in the spring of 2012, a major RF upgrade in the Main Injector was accomplished, reducing its cycle time from 2.2 s to 1.67 s. Additionally, the Recycler ring, which was key to antiproton generation for the Tevatron, was converted to a proton accumulator so that protons can be integrated and stored during the Main Injector ramp from 8 GeV at injection to 120 GeV.

At the same time, the NuMI beamline underwent a transformation to accommodate the higher proton intensities required for NOvA. The neutrino target and focusing horns were replaced and repositioned. The new beam provides higher-energy neutrinos on-axis, but at 14 mrad off the beam axis – where the NOvA detectors are located – the neutrino energy spectrum is peaked narrowly at 2 GeV, the perfect energy for the long-baseline oscillations that NOvA will study.

Beam began circulating again in the Main Injector in September 2013 and work started on commissioning the new accelerator in the Recycler ring. The Recycler is now normally included in operations, and work is underway to "slip stack" routinely in this new machine – a delicate manoeuvre where one bunch is injected then shifted to a different orbit to make room for a second bunch in the same RF bucket. Once the two bunches are merged, they are accelerated together. This work is expected to bring the NuMI intensity to 450 kW by the end of the year, and ongoing upgrades to the Booster ring that feeds this complex are expected to bring the intensity to 700 kW within another year. Since coming back up from the shutdown, the complex has achieved a peak beam power of more than 300 kW and delivered almost 2.5×10^{20} protons to NOvA and the other two neutrino experiments sharing the beam, MINOS+ and MINERvA.

In addition to an intense beam, NOvA also requires a massive far detector and a functionally identical near detector. Like all neutrino detectors, the NOvA detector must be big to overcome the small size

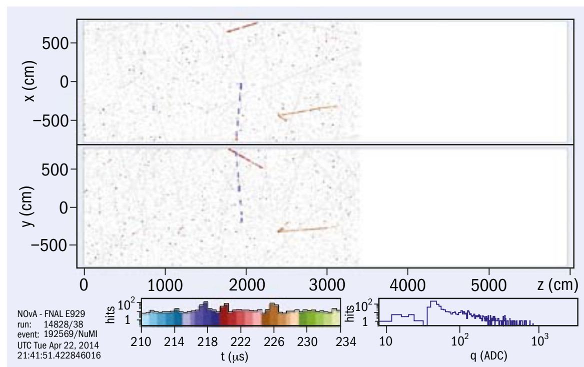


Fig. 4. An event display showing a charged-current ν_μ candidate in the far detector. Two cosmic rays are also seen in the detector during the 10 μs beam spill. This event was recorded at a time when only the front half of the detector was instrumented.

of the neutrino-interaction cross-section and the 810 km distance from the neutrino source. Being big, however, is not enough. The detector must also be highly segmented to prevent the numerous cosmic rays that cross the detector from interfering with neutrino events from Fermilab. Furthermore, to separate electromagnetic showers from electron-neutrino events from similar showers from other sources, especially the decays of π^0 mesons, heavy materials of high atomic number (Z) such as steel – which are normally used to build large structures – have not been employed.

The NOvA detectors (figures 1 and 2, pp 30–31) are a unique solution to the particular challenges of observing ν_e appearance using the NuMI neutrino beamline. The NOvA far detector is a 14,000 tonne detector, using 9000 tonnes of liquid scintillator – the largest quantity of liquid scintillator ever produced for a physics experiment – to record the tracks of charged particles. The scintillator is contained in a $15.6 \times 15.6 \times 60\ m^3$, 5000-tonne PVC structure constructed from modules assembled at a factory operated by collaborators at the University of Minnesota. A crew of more than 700 undergraduate students directed by 10 full-time staff members ran the factory. These pieces were shipped to the Ash River Laboratory in Northern Minnesota, where another 45 full-time staff members built the 28 free-standing blocks that make up the detector. The 190-tonne

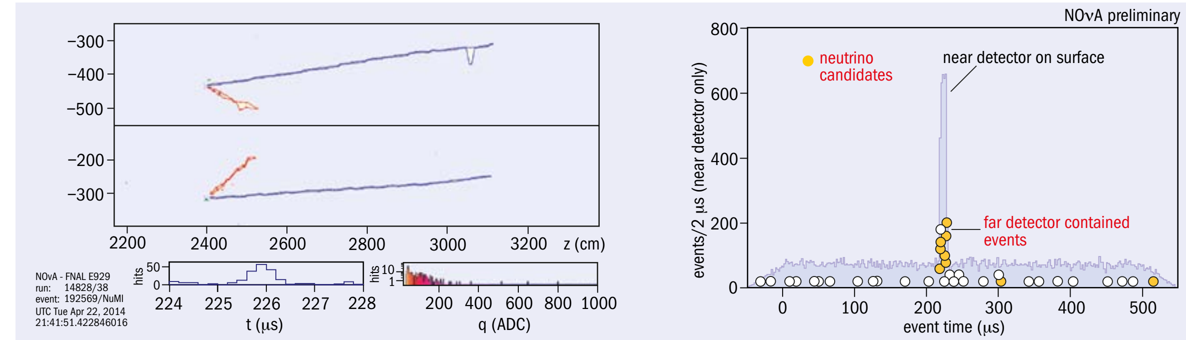


Fig. 5. Left: The reconstructed event from figure 3. Right: Timing distribution of other candidate neutrino events found in the far detector.

blocks were constructed horizontally on an enormous table, which later pivoted them into a vertical position and placed them in the experimental hall.

In addition to containing the scintillator, the PVC structure segments the detector into 4 cm × 6 cm × 15.6 m channels. Light produced in these channels by the charged particles that traverse them bounces 10 times, on average, before it is captured in a wavelength-shifting fibre. To ensure that enough light is captured in the fibre, a special PVC formulation with enhanced reflectivity had to be developed. The large size of the detector and the large number of channels required more than 10,000 km of wavelength-shifting fibre – enough to stretch from the supplier in Japan to the Ash River Laboratory in a single unbroken thread.

This large-scale assembly project is now finished. The last detector block was put in place in February of this year and the last of the 11 million litres of scintillator made for the experiment was delivered in April. While the task of outfitting the detector with electronics is continuing through the summer, the experiment recorded its first neutrino event in November last year, and has analysed millions of cosmic-ray tracks. This analysis has verified that the scintillator, PVC, fibre and electronics work together as designed to move the scintillation light from the far end of the detection channels to where it can be recorded. As figure 3 shows, the efficiency for detecting a minimum-ionizing particle crossing a cell at the furthest end from the read-out is above 90%, which is key to the tracking and particle-identification performance of the detector.

First events

Cosmic-ray interactions are an excellent source for detector calibration, but they are also a potential background to the neutrino selection. While the NuMI beam is delivered in regular bursts, 10 μs in duration, the high cosmic rate on the surface means that about 1.5 cosmic interactions are expected in the detector during the spill. On the other hand, after oscillations, a NuMI neutrino interacts in the far detector once every 12,000 spills, or only about once every four hours. Containment and directional cuts suppress the cosmic rate by about a factor of 10^5, with only minimal loss of neutrino events. Figure 4 shows a charged-current ν_μ interaction identified in the NOvA far detector, along with two cosmic-ray muons zipping through during the beam spill. Figure 5 shows the same event, reconstructed, as well as a timing distribution of other neutrino candidates found in the far detector. The neutrino candidates pile up at the arrival time measured in the NOvA prototype detector delayed by the neutrino flight time between the two sites, confirming that NOvA can identify neutrinos among the cosmic-ray backgrounds.

While relatively simple cuts can be used to separate beam neutrino events from cosmogenic events, further suppression of cosmic rays is required to achieve the oscillation physics goals. Multivariate event-selection algorithms tuned to recognize the differing topologies of ν_μ and ν_e charged-current and and neutral-current interactions suppress the cosmic-ray background rate by a further two orders of magnitude. Data collected when the beam is known to be off confirm that the necessary level of rejection can be achieved: the cosmic-ray background in a one-year exposure is predicted to be one event in the ν_μ sample and 0.5 events in the ν_e sample, well below the expected signal rates of 75 and 15 neutrinos in these samples.

The NOvA collaboration is now eagerly awaiting data from the near detector, which are needed to measure the beam composition and energy spectrum before oscillations have developed. The near-detector data will set the background expectation in the far detector for the ν_e appearance channel, and determine the unoscillated event rate as a function of energy for the ν_μ disappearance channel. In May, one sixth of the full near detector was turned on for the first time, and neutrinos were seen in the first spills. NOvA researchers are looking forward to an exciting summer.

Résumé

NOvA pose un nouveau regard sur les oscillations de neutrino

La nouvelle expérience sur les neutrinos NOvA, installation-phare de Fermilab, a enregistré ses premiers neutrinos et se prépare maintenant à des mesures de précision de l'apparition de neutrinos électroniques et de la disparition de neutrinos muoniques. Ces données contribueront à élucider les éléments qui demeurent inexpliqués pour mieux comprendre des masses et du mélange des neutrinos. NOvA utilisera deux détecteurs pour mesurer les probabilités d'oscillation dans le faisceau de neutrinos muoniques NuMi de Fermilab : l'un à Fermilab et un autre à 810 km de là, à Ash River, dans le Minnesota. La collaboration attend avec impatience que ces deux détecteurs soient achevés.

Mark Messier, Indiana University, and **Patricia Vahle**, William & Mary.

Faces & Places

COLLABORATION

Turkey to become associate member state of CERN

On 12 May, CERN and Turkey signed an agreement admitting Turkey to CERN associate membership, subject to ratification by the Grand National Assembly of Turkey – the Meclis.

Turkey was granted observer status at CERN in 1961, and Turkish physicists are today active in the ALICE, ATLAS, CMS and LHCb experiments at the LHC. They are also involved with CAST, NA63 and OPERA, as well as with experiments at the ISOLDE facility. Turkey operates a Tier-2 centre of the Worldwide LHC Computing Grid, and 110 Turkish scientists are registered users of CERN's facilities.

Turkey's associate membership will allow it to attend CERN Council meetings and open up industrial collaborations. Turkish scientists can also become CERN staff members and participate in CERN's training and career-development programmes.

Taner Yildiz, Turkish minister for energy and natural resources, left, and CERN's director-general, Rolf Heuer, together with the signed agreement. (Image credit: CERN-PHOTO-201405-100-89.)

APPOINTMENTS

All change at Argonne

Harry Weerts, in charge of physical science and engineering at Argonne. (Image credit: ANL.)

Harry Weerts has been named as the interim associate laboratory director for physical sciences and engineering at Argonne National Laboratory. Director of Argonne's high-energy-physics division, he now oversees the laboratory's interdisciplinary research programmes in physics, chemistry, material science and nanotechnology. He takes over from Peter Littlewood, who has become director of the laboratory.

Weerts' recent research has focused on linear-collider physics and developing detector concepts for a linear collider. Previously, he worked in neutrino physics at CERN and on hadron-collider physics with the D0 experiment at Fermilab's Tevatron, serving as spokesperson for the experiment for six years. Before coming to Argonne, he spent 23 years on the physics faculty at Michigan State University.

At the same time, the high-energy-physics deputy director, Rik Yoshida, has agreed to serve as interim director for the division. Yoshida has been a researcher at both the LHC at CERN and at DESY, where he served as the spokesperson of the ZEUS experiment.

Battiston to head Italian Space Agency

Roberto Battiston, new president of the ASI. (Image credit: Michele Famiglietti/ SpacePart12.)

Stefania Giannini, minister of education, university and research, has appointed Roberto Battiston as president of the Italian Space Agency (ASI).

A graduate of the Scuola Normale of Pisa, Battiston is professor of experimental physics at the University of Trento, where he moved in 2012 to set up a new institute for astroparticle physics and technology. He has worked for more than 30 years, on behalf of INFN, within international collaborations in experimental particle physics and, more recently, on the study of cosmic rays in space. In particular, he is deputy spokesperson for the Alpha Magnetic Spectrometer, installed on the International Space Station in May 2011 (*CERN Courier* October 2013 p22).

Battiston, who succeeds Aldo Sandulli, was identified through a procedure carried out by a selection committee set up last February. From a total of 55 applications, the committee selected five candidates that were presented to the minister for her choice.

AWARDS

Knighthoods for Kibble and Virdee

Tom Kibble and Tejinder (Jim) Virdee, both of Imperial College London – and both well known for their roles in the prediction and detection of a Higgs boson – have been awarded the UK's highest honour in the 2014 Queen's birthday honours.

Kibble, who receives a knighthood for "services to physics", is distinguished for his ground-breaking research in theoretical physics across nearly six decades. He is one of the theoretical physicists whose work in the early 1960s became a key piece of the Standard Model, through giving mass to the W and Z bosons via a symmetry-breaking mechanism that would require a new particle, dubbed the Higgs boson. He has also made significant contributions to the study of the dynamics of symmetry breaking near phase transitions with many applications, including the formation of structure in the universe and vortices in helium-3.

Virdee spearheaded the concept and design of the Compact Muon Solenoid (CMS) experiment, which together with ATLAS found the first evidence for the existence of a Higgs boson in 2012. Virdee oversaw the construction of CMS and was deputy spokesperson then spokesperson for the collaboration until 2010. His knighthood, awarded for "services to science", also recognizes his work campaigning for and promoting better science education in Africa and India.

Jim Virdee, right, shows Tom Kibble the results from CMS on the discovery of a Higgs boson, announced in July 2012. (Image credit: M Sanch/Imperial College.)

In the same honours list, David Delpy, chief executive of the Engineering and Physical Science Research Council (EPSRC) until March this year, received the honour of Commander of the British Empire (CBE) "for service to engineering and scientific research". EPSRC is responsible for funding the UK's contributions to research in nuclear physics at CERN, in particular at the ISOLDE facility, the neutron time-of-flight facility and the Antiproton Decelerator.

In a ceremony held on 15 May, Tom Kibble, left, received the Albert Einstein Medal 2014, awarded by the Albert Einstein Society, Bern, to honour extraordinary achievements related to Einstein's legacy. Kibble is honoured in recognition of many contributions, including those relating to symmetric properties of the non-Abelian gauge theories that underlie the Standard Model of particle physics, to mechanisms of the symmetry-breaking and synthesis of new elementary particles and to spontaneous symmetry-breaking in cosmology. He received the medal from Hans-Rudolf Ott, right, president of the Albert Einstein Society. (Image credit: S Widmer.)

● For more about Kibble's work, see Books received, p49.

CERN Courier July/August 2014

Faces & Places

Markov Prize recognizes pioneers in theoretical astrophysics and cosmology

Igor Tkachev, of the Institute for Nuclear Research (INR) of the Russian Academy of Sciences (RAS), Moscow, and Alexander Dolgov, of the Alikhanov Institute for Theoretical and Experimental Physics, Moscow, and INFN, have been awarded the 2014 Markov Prize. They received the award at the 2014 Markov Readings, held at the INR on 14 May, for "pioneering works in the field of theoretical astrophysics and cosmology".

The laureates are both well known in the fields of elementary particle physics, astrophysics and cosmology. Tkachev has made significant contributions to the development of the theory of the early universe, while Dolgov elaborated the kinetic theory of elementary particles, including neutrinos, in the expanding universe. The Markov Prize was established by INR RAS in commemoration of Moisey Markov, who made pioneering contributions to neutrino physics, as well as to physics at the boundary between particle physics and cosmology.

Left to right: The 2014 Markov Prize laureates, Igor Tkachev and Alexander Dolgov, with the director of INR, Victor Matveev. (Image credit: INR.)

SYMPOSIUM

Berkeley honours Nygren's ingenuity

David (Dave) Nygren, of Lawrence Berkeley National Laboratory (LBNL), has a distinguished record of detector-instrumentation inventions and innovations, which have transformed research in particle and nuclear physics and in cosmology. To honour him for his ingenious designs, mark his impending retirement and, incidentally, celebrate his 75th birthday, more than 150 physicists from around the world gathered at LBNL on 2–3 May for The Art of Experiment – A Symposium to Celebrate Forty Years of Advances 1974–2014.

Welcomes from the director of LBNL's physics division, Natalie Roe, and laboratory director, Paul Alivisatos, were followed by speakers who were invited to "look at current and emerging topics at the interface between physics and experimental techniques and methods, for subjects related to Dave's research". Between them, they covered a varied selection of topical subjects to show "ways in which physics is currently, or will be, enabled by new and creative innovations in instrumentation and methods". To recognize his work on CP violation, Nygren's early career was recalled by his mentor and then colleague, Jack Steinberger.

It was in 1974 that Nygren invented the time projection chamber (TPC), a simple and brilliantly conceived device to record 3D tracking data for charged particles in a large gas-filled volume equipped with parallel electric fields (in which ionization electrons drift) and magnetic fields (in which charged reaction products move on helical paths). The first TPC, built at Berkeley, was used in the PEP-4 experiment at SLAC to study e^+e^- annihilation interactions at, what was then, high energy. That history was the subject of a talk and a discussion by a panel of six veterans ("survivors") of the difficulties and successes of prototyping, building and operating the TPC.

TPCs were essential elements in the ALEPH and DELPHI experiments at CERN's Large Electron–Positron collider and are now used in ALICE at the LHC, ICARUS (filled with liquid argon rather than gas) at CERN and the Gran Sasso National Laboratory, and STAR at the Brookhaven National Laboratory. These and other gaseous-detector technologies were the subjects of talks, including one on the history of the field – which is still evolving brilliantly with ever-improving performance 45 years after having been introduced to particle physics – that concluded with "...to be continued".

TPCs are central to a number of past, current and proposed approaches to settle two of the most perplexing problems to have beset science for some years – the nature of dark matter and of neutrinos. Experiments that use TPC technology in searches for weakly interacting massive particles (WIMPs), which are leading candidates for dark-matter particles, and for neutrinoless double beta decay – to determine if antineutrinos are identical to, or different from, neutrinos – were the subjects of talks on experimental searches that have been or are now operating, as well as others planned for various global sites. Two of those showcased the latest of Nygren's conceptual art: a high-pressure xenon-gas TPC for the NEXT experiment, in Spain, and an approach to detection of WIMP directionality. Nygren is a member of the now extensive international NEXT collaboration.

Dave Nygren: "inspirational and wise beyond his years". (Image credit: Jerry Przybylski.)

Nygren's early work on pixel detectors for the ill-fated Superconducting Super Collider (SSC) led to the development of smart pixel arrays, as now used in the ATLAS detector's precision-tracking system at the LHC. Pixel history, current status and R&D were reported by a speaker who noted that "Half-baked ideas have been a constant of pixel-detector development and there is [a] shortage of them today." Nygren pushed the idea that fully depleted charge-coupled devices (CCDs) could be developed from the silicon-detector R&D done for the SSC. The LBNL CCD is now the standard for astronomical cameras and spectrographs. That development story was presented thoroughly, as were others that dealt with detector techniques for the projected International Linear Collider ▷

CERNCOURIER
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in Japan or the US and the ARIANNA neutrino-astronomy observatory in Antarctica. Perhaps less familiar to particle and nuclear physicists is Nygren's application of silicon-strip detectors to X-ray imaging, which has become a widely used method for digital mammographic screening in Europe, Japan and Australia, and is being adopted globally – the basis of two talks at the symposium.

Talks also reviewed Nygren's obsession with better detector performance applied to neutrino astronomy in Antarctic ice by IceCube, and in the water of the Mediterranean in NESTOR. One concluding remark – "Dave, it could not have been done without you!" – was a common theme. A view from the US Department of Energy, the prime supporter of much of the research celebrated at the symposium, was provided by Jim Siegrist, associate director, Office of High Energy Physics, Office of Science. He ended with another common theme: "Dave is truly remarkable. I am at a loss for words. He is inspirational and wise beyond his years – which is getting really difficult."

Dinner was a Chinese-style banquet at a restaurant just west of Berkeley on the San Francisco Bay east shore, with a glorious view of the bay and its iconic sights. After dinner, Pier Oddone, former deputy-director of LBNL and former director of Fermilab, spoke of Nygren and the times, followed by LBNL's Bob Cahn, who read messages from a few of the people who were unable to attend the symposium.

The symposium closed with a broad, detailed survey of perspectives for further experiment.

● For recorded presentations, visit https://indico.physics.lbl.gov/indico/conferenceDisplay.py?confId=128.

Schools

JUAS celebrates 20th anniversary

Top: Participants at the celebrations for the 20th anniversary of JUAS gather for the "family photo". Above: Members of the round-table discussion. (Image credits: Chantal Argoud/ESRF-Grenoble.)

The Joint Universities Accelerator School (JUAS) celebrated its 20th anniversary at the Laboratoire de Physique Subatomique et de Cosmologie (LPSC) in Grenoble on 25 April. The event brought together more than 100 scientists, lecturers, students and institutional partners to share a special day dedicated to the school, and provided an opportunity to look back on the past 20 years and to debate the future.

The morning session was opened by Annick Billebaud, director of LPSC, with welcoming remarks and a brief history of the laboratory where JUAS was conceived in the early 1990s. She was followed by Hans Hoffmann, president of the European Scientific Institute (ESI), who presented the schools organized by the institute.

Alex Mueller, research director at CNRS/IN2P3, then discussed the challenges faced by today's accelerators and the technology paths currently explored for high energies and high powers. In his talk, Steve Myers, former director of accelerators and technology at CERN, reviewed particle accelerators in the 20th century, as well as those foreseen for the 21st century, with many applications other than in high-energy physics.

The coffee break provided an enjoyable moment to meet past and present colleagues and to exchange ideas. After the break, Luigi Palumbo, director of the Department of Applied Sciences for Engineering at Rome's La Sapienza University, presented the many facetted needs of accelerator training in the world. To conclude the morning, Louis Rinolfi, director of JUAS, presented the past, present and future of the school, paying tribute to former JUAS directors and all of the partners who have contributed to the school's success during the past 20 years.

The afternoon session started with a round-table discussion chaired by Frédérick Bordry, CERN's director of accelerators and technology. The participants included the morning's speakers together with Philip Burrows, of Oxford University and spokesperson of the international Compact Linear Collider (CLIC) accelerator collaboration, and Pantaleo Raimondi, director of the Accelerator Department at the European Synchrotron Radiation Facility (ESRF).

The ensuing lively debate confirmed both the real needs and the R&D opportunities that are raised by current particle accelerators and future projects. The pertinent interventions by students were an encouraging sign that the new generation of accelerator scientists is well aware of the challenges that lie ahead.

The day ended with a visit to the ESRF. After a presentation of the synchrotron radiation machine in the recently opened visitor centre, participants were able to discover the control room, experimental beam lines and other equipment. To conclude, Bordry, Rinolfi and all of the ESI team expressed their sincere gratitude to all who took part in and contributed to this important day for JUAS.

High-energy physics carries on in Bosnia and Herzegovina despite the floods

Students and lecturers at SSHEMP 2014 express their appreciation that the school proved to be stronger than the floods. (Image credit: Ilja Doršner.)

The fifth edition of the Sarajevo School of High Energy and Medical Physics (SSHEMP 2014) took place at the University of Sarajevo on 19–24 May, against a backdrop of one of the biggest natural disasters ever to have affected Bosnia and Herzegovina and neighbouring countries.

The unprecedented floods and landslides did not prevent advanced undergraduate and graduate students interested in high-energy and medical physics from finding inventive ways to reach Sarajevo and attend the school. This was a real challenge, considering the fact that the closures of roads, bridges and border crossings in Bosnia and Herzegovina coincided with the start of the school, which attracted 60 students and lecturers from Albania, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Egypt, France, Macedonia, Norway, Poland, Rumania, Serbia, Slovenia, Switzerland and Turkey.

The support of CERN, together with that of ICTP, PARSECO, UNESCO through Physique sans Frontières and the French Embassy in Sarajevo, has been particularly important in organizing the school and giving it its international status.

● For more about SSHEMP 2014, visit http://www.pmf.unsa.ba/fizika/SCHOOL/HOME.html.

CAS covers power converters

Participants at the school in Baden. (Image credit: Markus Fischer/PSI.)

The CERN Accelerator School (CAS) and the Paul Scherrer Institute (PSI) organized a specialized course on power converters at the Hotel du Parc in Baden, Switzerland, on 7–14 May. Following some recapitulation lectures on accelerators and the requirements on power converters, the course covered a range of topics related to the different types of power converters needed for particle accelerators. Topical seminars completed the programme.

The successful course was attended by 84 students representing 21 nationalities. While most of the participants were from European countries, others were from Brazil, Canada, China, Iran, Jordan, Thailand and the US. Sponsoring in the form of scholarships was offered by CAENels, OCEM and CERN to students who would otherwise have been unable to attend.

Feedback from the participants was very positive, reflecting the high standard of the lectures and teaching. In addition to the academic programme, the participants also had an opportunity to take part in a full-day visit to ABB, a major Swiss manufacturer of power converters, and PSI and an excursion to the Rhein Falls.

● Forthcoming CAS courses will be a specialized school on plasma-wake acceleration to take place at CERN on 23–29 November and a US-CERN-JAPAN-RUSSIA Joint International Accelerator School course on beam loss and accelerator protection to be held in Newport Beach, California, on 5–14 November. For more information on both of these schools, visit www.cern.ch/schools/CAS.

Visits

Greek president **Karolos Papoulias**, seated, visited CERN on 3 May, where he was shown the ATLAS control room by ATLAS Greek team leader, **Evangelos Gazis**, before visiting the ATLAS experimental cavern and LHC tunnel. He also met with the Greek community at CERN. (Image credit: CERN-PHOTO-201405-095 – 28.)

Phillip Paulwell, Jamaican minister of science, technology, energy and mining, signed the guestbook alongside CERN's head of international relations, **Rudiger Voss**, during his visit on 14 May. He was shown the ATLAS experimental cavern and the LHC tunnel. (Image credit: CERN-PHOTO-201405-105 – 2.)

On 15 May, **Pavel Bělobrádek**, Czech Republic deputy prime minister for science, research and innovation and chairman of the Research, Development and Innovation Council, visited the LHC tunnel, and ATLAS and ALICE experimental caverns. (Image credit: CERN-PHOTO-201405-104 – 13.)

European commissioner for research, innovation and science, **Máire Geoghegan-Quinn**, centre, came to CERN on 19 May. She was shown the CMS experimental cavern by collaboration spokesperson **Tiziano Camporesi**, left, accompanied by CERN's director-general. (Image credit: CERN-PHOTO-201405-103 – 42.)

Vytenis Andriukaitis, Lithuanian minister of health, left, was welcomed by CERN's director-general on 20 May, before being shown the CMS experimental cavern. (Image credit: CERN-PHOTO-201405-107 – 4.)

On 21 May, **His Majesty Philippe**, King of the Belgians, left, was shown the LHC tunnel by **Frédérick Bordry**, director of accelerators and technology, centre, pointing, accompanied by Nobel laureate **François Englert**, right. (Image credit: CERN-PHOTO-201405-109 – 23.)

CERN60

Synchrocyclotron named EPS Historic Site

CERN's first accelerator, the Synchrocyclotron (SC), has been named a European Physical Society Historic Site. The honour came during the SC's inauguration as a new visitor point on 19 June, at a ceremony for CERN Council.

When it started operation in 1957, the SC was the highest-energy particle accelerator in Europe, and during its 33 years of service it provided many important physics results. Shut down in 1990, it has lain dormant since (*CERN Courier* March 2014 p38). Now, CERN's Education and Radiation Protection groups have jointly overseen an extensive refurbishment project to turn the SC into a new exhibition point for visitors.

On the walls, timelines show important moments in CERN's history, together with associated tools and artefacts. But what gives the accelerator a new lease of life is a 3D projection system. An intricate system of eight projectors displays six different images simultaneously onto the accelerator's surfaces, projecting beautifully crafted animations. Visitors see protons flit across the room and magnetic fields expand in clouds of blue haze, as a narrator explains a typical SC run. Each part of the process is punctuated with a 3D display, giving a clear picture of how the accelerator worked.

The Synchrocyclotron bathes in a blue neon glow. The large spanners on the wall to the right were used in the 1950s to tighten the bolts on the accelerator's red magnet (Image credit: Jacques Herve Fichet/CERN.)

On 31 May, CERN took part in the parade celebrating Geneva's 200th anniversary, with a superconducting magnet from the LHC travelling through the city's narrow streets on a 20-m lorry. The event celebrated the bicentenary of Confederate troops landing at the Port Noir, heralding Geneva's integration into the Swiss Confederation. The parade featured 1200 participants and took onlookers back in time to 1814 – complete with police officers and firefighters in period uniforms and vehicles. With CERN's presence, the 21st century was not forgotten, and the organization used the occasion to showcase its 60th anniversary. (Image credit: CERN-PHOTO-201406-113 – 35.)

● *For more about the 60th-anniversary events, visit http://cern60.web.cern.ch/.*

New products

Elsys Instruments has expanded its family of LAN-controlled transient recorders with a new series of high-resolution PCIe data-acquisition cards. The new data-acquisition waveform-digitizing products deliver prime performance in applications where the acquisition of high-speed, high-resolution and high-precision waveform data is of importance. For additional information, tel +41 56 496 0155, e-mail thomas.berger@elsys.ch or visit www.elsys-instruments.com/products/tpce-le.php.

Goodfellow now offers silicon-carbide foam, which provides the hardness, high-temperature durability and performance of solid silicon carbide, but in a lightweight and versatile foam structure. The foam is available from stock with 24 pores/cm, a bulk density of 0.29 g/cm^3, porosity of 91% and thickness of 10 mm. Other porosities, densities and dimensions may be available upon request. For more information, tel +44 1480 424 800, e-mail info@goodfellow.com or alternatively visit www.goodfellow.com.

Keithley Instruments, Inc., has introduced two high-voltage power supplies optimized for device and materials testing and research in high-energy physics and materials science. The Model 2290-5 5kV Power Supply and Model 2290-10 10kV Power Supply are suited for high-voltage breakdown testing of power semiconductor components. Keithley has also announced the new Series 2260B Programmable DC Power Supplies, designed for benchtop, embedded and manufacturing test applications that demand higher power and performance. The series includes two 360 W and two 720 W models, offering a range of output levels, combined with LAN and USB connectivity and an optional GPIB interface. For further information, visit www.keithley.com.

The **Kurt J Lesker Company** has recently launched a new Feedthrough Selection Guide on its website. The selection guide helps users to select the proper feedthrough for their application, based on their specific requirements. This visual guide makes selecting the correct power, instrumentation, thermocouple, liquid, gas, liquid nitrogen, ceramic break, or fibre-optic feedthrough quick and easy. For additional information on this new guide, tel +1 412 387 9200, e-mail salesus@lesker.com or alternatively visit www.lesker.com.

OBITUARY

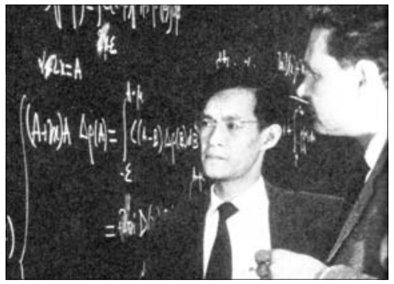
Robert Vinh Mau 1931–2014

Robert Vinh Mau, professor emeritus at the Université Pierre et Marie Curie, Paris-Jussieu, passed away on 25 April at the age of 82.

Mau – his first name in Vietnamese – was born in Hué, a member of the Vietnamese imperial family. He studied for his baccalauréat in Saigon and then moved to France – first to Grenoble for his undergraduate studies, where he was handicapped by tuberculosis, and then to Paris. He obtained his PhD under Roger Nataf in Orsay, on Coulomb effects in inner bremsstrahlung.

In 1960, Nataf sent him to work with me at CERN, where we worked together on the analyticity of amplitudes in potential scattering, and quickly became friends for life. Mau then went to Rome and Bordeaux, where with B Bonnier in 1967 he found a fundamental lower bound on the pion–pion scattering length. (This was later considerably improved by Irinel Caprini and Petra Dita.) Finally, Mau became professor at the university in Paris-Jussieu, where he had important functions, as well as at CNRS.

Mau's major contribution was to obtain a nucleon–nucleon potential. Since Hideki Yukawa postulated what turned out to be the pion, there had been many attempts to derive this potential. Working with Noel Cottingham, who he had met at CERN in 1960, Mau followed the proposal made by John Charap and Sergio Fubini. They obtained, with the help of excellent collaborators Jean Côté, Benoît Loiseau, Michel Lacombe, Pierre Pirès, Jean-Marc Richard and Roland de Tourreil, what is called the "Paris potential", which was and remains an extraordinary success, fitting an immense amount of data. (In 1981, Mau sent Jean-Marc Richard to work with me at CERN, with whom I still have a wonderful collaboration.)



Robert Vinh Mau and André Martin in discussion at CERN in 1960. (Image credit: CERN.)

For this work on the potential, Mau received the Petit d'Ormoy prize of the French Académie des sciences in 1983 and the Alexander Von Humbolt prize in 1986. He also made other contributions with possible cosmological consequences (see, for example, his article with Nicolas Borghini in *La Recherche*, no. 337 p52).

Mau was a friend of eminent scientists, such as Nobel laureates Julian Schwinger and Leon Cooper. He also liked to travel, for instance to Stony Brook and Berkeley, but went once only back to Vietnam, to a conference in Hanoi. There he spoke in English to be understood by everyone, while the Russians spoke only in Russian. He also visited Saigon and found his house in ruins. His last years were painful, not only for himself but also for his wife, Mylène, who showed admirable devotion. We will miss him a great deal.

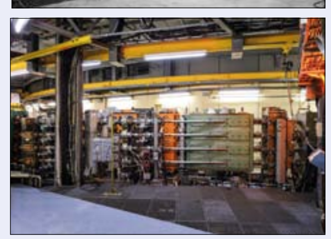
● *André Martin, CERN, with acknowledgement to Benoît Loiseau for allowing use of his speech at the funeral.*

NEW PRODUCTS CONTINUED

Murata has announced the MTU2 series of ultra-miniature surface-mounted 2 W DC–DC converters from Murata Power Solutions, measuring 8.2 × 8.4 × 8.5 mm^2 with a 0.69 cm^2 footprint. With a typical conversion efficiency of 85% across the full load range and a power density of 3.403 W/cm^3, the MTU2 series is available with either a single- or dual-output voltage. For more information, contact Aya Tonooka, tel +44 1252 811666, e-mail atonooka@murata.co.uk or visit www.murata.eu.

VadaTech has announced an 8U-high chassis compliant with the MicroTCA.4 specification that offers N+1 redundant power to 4400 W. MicroTCA.4 systems utilize double modules with an RTM connector for rear I/O. With specially designed power modules, the VT813 chassis has four 1100 W power supplies in an N+1 redundant power configuration. By aligning the compact power supplies on the side of the card cage, the chassis can provide 12 double-module, mid-sized slots. For more details, visit www.VadaTech.com.

60 YEARS/ANS CERN



*The Proton Synchrotron Booster (PSB) is one of the smaller machines in CERN's accelerator complex. The concept behind it dates back to the mid-1960s, when ideas to improve the performance of the PS by raising its output beam intensity from 10^{12} to 10^{13} protons per pulse were being considered. One of a kind, it consists of four superimposed synchrotron rings, into which the beam from the linac is successively injected. The four beams are then accelerated and eventually recombined after extraction before entering the PS. The top view was taken in October 1972, around the time the PSB began to feed the PS, just five months after accelerating its first protons. The photograph is taken at the position where beams emerge from the four levels of the booster on the left and are brought progressively to the level of the PS. Since then, the PSB has undergone several upgrades and in the LHC era (below right) it is operating with its highest availability and flexibility, and far beyond its original design specifications. The aim is to operate the PSB throughout the lifetime of the LHC, and ensure that it remains one of CERN's backbone accelerators for the foreseeable future (*CERN Courier *September 2012 p33). (Image credits: CERN-AC-7210021 and CERN-PHOTO-201405-098-51.)*

Recruitment

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

INSTITUT DE FÍSICA D'ALTES ENERGIES
Consorci de la Generalitat de Catalunya
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CALL FOR APPLICATIONS: DIRECTOR OF IFAE

The Institute of High Energy Physics (IFAE), **www.ifae.es/eng** is a consortium of the Universitat Autònoma de Barcelona and the Generalitat of Catalonia. IFAE is part of the Catalan public network of research Institutes, CERCA (**www.cerca.cat**).

IFAE conducts experimental and theoretical research at the frontier of fundamental physics, namely in Particle Physics, Astrophysics and Cosmology. IFAE also works at the cutting edge of detector technology, applying its know-how to Medical Imaging and other applied research fields. It maintains a fruitful collaboration with its spinoff company, X-Ray Imatek.

In 2012, IFAE was granted the Severo Ochoa award, given by the Spanish government to a few leading national research centres.

Candidate profile and contact information

IFAE is seeking applicants with a distinguished record of scientific excellence and the innovative thinking necessary to lead a dynamic organisation. A PhD or comparable degree, high international visibility in IFAE's field(s) of activity and significant research management experience are required. Salary will be commensurate with qualifications and consistent with IFAE management's salary scale.

More information, including a description of the Director's post and responsibilities, is at **www.ifae.es/eng/work/open-positions.html**.

The successful candidate may be offered an indefinite position as Full Research Professor. The appointment as Director will be for a period of 4 years, which could be extended. Applicants should send a CV and a cover letter by e-mail to the Director of CERCA, at **applications@cerca.cat**, citing as the subject "IFAE Director call".

The deadline for applications is October 10, 2014.

The Cockcroft Institute
of Accelerator Science and Technology

The Universities of Liverpool, Lancaster and Manchester
The Cockcroft Institute

Director

Salary Negotiable

The Cockcroft Institute (http://www.cockcroft.ac.uk/) is a unique international centre specifically responsible for research and development in particle accelerators, colliders and light sources for advancing the frontier of particle and nuclear physics, photon sciences and various applications to society in the areas of health, medicine, energy and security. The Institute is a partnership between the Universities of Liverpool, Manchester and Lancaster and the Science and Technology Facilities Council.

We are seeking to appoint a Director of the Institute who will grow its reputation as a world-leading centre for accelerator science. Reporting to the Institute Board, the Director will work with the partners to develop strategy for the Institute and manage all aspects of its implementation. You will have a successful track record in accelerator science or a related field and have demonstrated ability in leadership in a university or research organisation. The role of Director will be for 5 years initially, and will be offered in combination with a permanent professorial appointment in one of the partner universities.

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Job Ref: A-565563/CC **Closing Date: 1 September 2014**

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The Departments of Mathematics and Physics at the University of California, Davis invite applications for four full-time faculty positions to launch a new research initiative: The Physics and Mathematics of the Universe. Applications will be considered for appointment at the level of Assistant Professor, Associate Professor or Professor; appointments will be made either in the Mathematics or Physics Department, or jointly between the two departments, to be determined on a case-by-case basis.

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This program will benefit from synergies with our strong research programs in high energy physics, gravity, cosmology, geometry, topology and mathematical physics.

Applicants must have a Ph.D. in physics or mathematics and the ability to teach effectively at both undergraduate and graduate levels. Demonstrated success in an active research program in physics or mathematics is essential.

Due to the large number of positions to be filled, applications will be evaluated starting October 10, 2014. To ensure full consideration, applications should be received by this date. The positions will remain open and applications will be accepted until the search is complete. Applications should be submitted online via the job listing PMUFAC2014 on http://www.mathjobs.org, and should include a cover letter, CV, publication list, research and teaching statements, and letters of recommendation from at least four references.

Inquiries may be addressed to PMU Search Committee Chair, Department of Physics, University of California, One Shields Ave, Davis, CA 95616, or by e-mail to **pmusearch@ucdavis.edu**. Further information about the departments may be found on our websites at **http://www.physics.ucdavis.edu** and **https://www.math.ucdavis.edu**.

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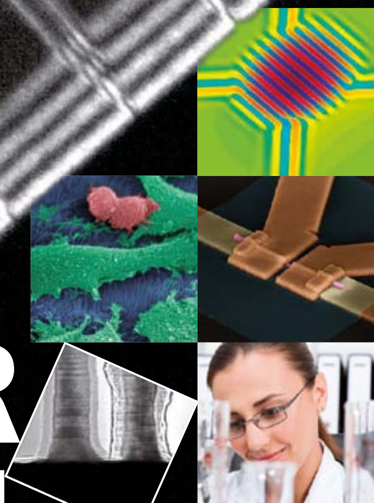

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Main image by Crispin Hetherington, Lund University: TEM image of an AlGaAs nanowire of 164 nm diameter. Design © www.tintin-blackwell.com, 2014

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Bookshelf

Summer Bookshelf

With summer well under way in the northern hemisphere, this Bookshelf features less technical books, and includes cartoons and even a film review – all on particle physics or closely related themes.

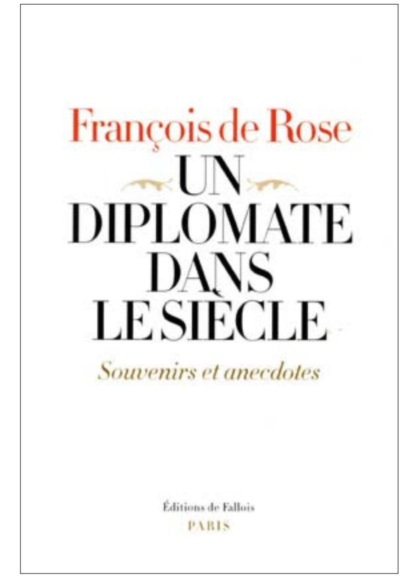
Un diplomate dans le siècle ; souvenirs et anecdotes

By François de Rose
Editions Fallois
Paperback: €10
Also available at the CERN bookshop

François de Rose est un grand témoin du XX^{e} siècle. Né en 1910, il a vécu les deux guerres qui déchirèrent l'Europe, la reconstruction de la paix, et tous les grands événements du monde d'hier. Diplomate, il a évolué dans les cercles des puissants et de leurs conseillers, et s'y fit des amis. Un jour de 1946, il fit la connaissance de Robert Oppenheimer et se lia d'amitié avec le célèbre physicien. Dès lors, il mit ses talents de diplomate au service des scientifiques qui voulaient reconstruire la science fondamentale en Europe. Il devint ainsi l'un des fondateurs du CERN. Il poursuivit ensuite sa carrière diplomatique, comme ambassadeur et spécialiste des questions stratégiques et militaires.

François de Rose n'écrivit jamais ses mémoires, bien que ses amis l'aient pressé de le faire. Mais à l'orée de ses 103 ans, il s'attela à la rédaction d'un recueil de souvenirs. Ce petit livre, intitulé *Un diplomate dans le siècle*, parut le 13 mars 2014. Dix jours plus tard, son auteur s'éteignait à Paris. Le CERN perdait son dernier fondateur.

François de Rose était un homme plein d'esprit, et un esprit libre. Son élégance et sa liberté de pensée scintillent au travers de ces anecdotes relatées au gré « *des caprices qui (lui) restent de mémoire* ». François de Rose raconte « *un temps que les moins de cent ans ne peuvent pas connaître* », il égrène avec humour des histoires qui ont marqué sa vie. Du baisemain à l'impératrice Eugénie en 1920 à la fête d'anniversaire d'Henry Kissinger en 2013, il est tout à fait fascinant de parcourir cette existence longue et riche, celle de l'un de nos contemporains qui fut aussi le contemporain de George VI et d'Albert Einstein. Cet humaniste livre une foule d'anecdotes sur la diplomatie au XX^{e} siècle, les hasards heureux ou malheureux, les grandes phrases et les petites histoires qui construisent l'histoire avec un grand « H ».



Le recueil fait une belle place au CERN, « *la plus belle plume à mon bicorne d'ambassadeur* », dit-il. François de Rose raconte ses rencontres avec Niels Bohr, Pierre Auger ou Robert Oppenheimer, de grands noms de la physique aujourd'hui entrés dans la littérature. Il relate comment il embrassa la cause du CERN et sa fierté d'avoir vu ce projet couronné de succès.

Écrit avec élégance, ce recueil s'apprécie comme une boîte de friandises, exquises et légères, aux saveurs d'antan.

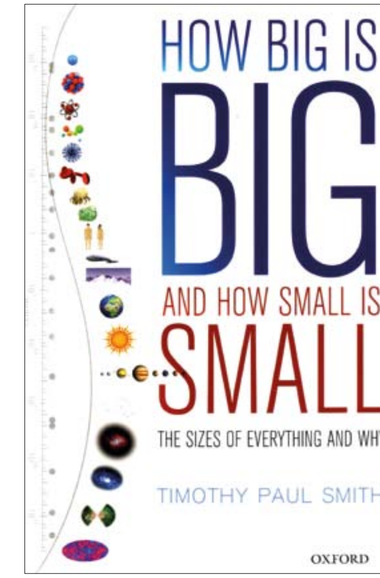
● *Corinne Pralavorio, CERN.*

How Big is Big and How Small is Small: The Sizes of Everything and Why

By Timothy Paul Smith
Oxford University Press
Hardback: £25
Also available as an e-book, and at the CERN bookshop

This book canters through the sizes and lifetimes of things, from the outermost reaches of the universe to the confined locality of quarks, telling us what is found where and why, and is, according to the publisher's website, suitable for "interested general readers as well as professional scientists" – a broad church.

In scanning 45 orders of magnitude, the author presents a wealth of information on "everything", from cosmology to string theory, with passing reference to cooking, football, square dancing and more. The narrative is exuberant and many of the facts



are little gems, but they are jumbled up, disordered and congested. The book reads like a series of digressions and there are enough typos and mistakes – bacteria and criteria are plural not singular, the shadow on a sundial is not cast by a gnome – to irritate anyone trying to stay the course.

Concepts seemingly pop up out of nowhere, reappearing again (and again and again) when the plot is all but lost. Much of the material is erudite, abstruse and irrelevant, such as "The delta particles Δ^{-} Δ^{-} Δ^{0} Δ^{+} are like neutrons and protons but with complex spin." Spin, complex or not, is not in the too-brief index, so the reader cannot check whether it has been defined earlier, or indeed anywhere, and the doubly charged member of this quartet is actually the Δ^{++}, although by now – page 123 – it is debatable whether even the most interested readers care. And why should they?

Some aggressive editing would have been in order, not only to fix imperfections and remove chunks of repeated or unnecessary text, but also to avoid slowing down the observant with infelicitous phrasing, for example, "A number of species in the new world and the old world have the same common name because, at least superficially, they look the same, for example the robin and the buffalo."

And in a cup of water drawn from an ocean today, how many molecules were in a cupful poured into the oceans long ago? After 10 pages of exhaustive and exhausting accounts of the work of Avogadro, Dalton, Gay-Lussac, Loschmidt and Maxwell, we arrive at the numbers. There are 3.3×10^{24} water molecules in a cup and 1.3×10^{22} cups in the oceans. So, 250 of the original molecules are in today's cup and, although not stated, the oceans contain 4.3×10^{46} water molecules. Yes? No! On the following page, "there are about 8×10^{45} molecules of water on Earth."

I was once told, if lost for affable words when asked for an opinion on something quite extraordinary, to say "astounding!" This book is astounding, which is a pity as it could and should have been excellent.

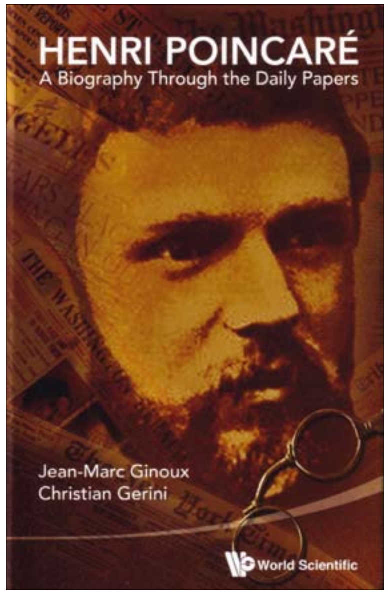
● *Peggie Rimmer, Satigny/Oxford.*

Henri Poincaré: A Biography Through the Daily Papers
By Jean-Marc Ginoux and Christian Gerini
World Scientific
Hardback: £19
E-book: £14

Henri Poincaré: A Biography Through the Daily Papers – where papers clearly include letters, because many are included – has caused some confusion in my mind. Turning the pages, it is hard to know where I am in time, and the events that are described seem to be of sub-relevance to what I was keen to read about. Two towering examples concern Poincaré's relation to politics and relativity.

I note that despite extensive discussion of his interaction with the daily press, there is only the briefest mention that Henri Poincaré had an influential cousin, Raymond Poincaré, who was president of France during the years 1913–1920 (and so covered the First World War), and before that a member of the French parliament, and on several occasions minister or prime minister. I had been hoping to learn how close Henri was to Raymond and how this impacted on the opinion of the French public on both of them – a genius mathematician and a powerful politician from the same family.

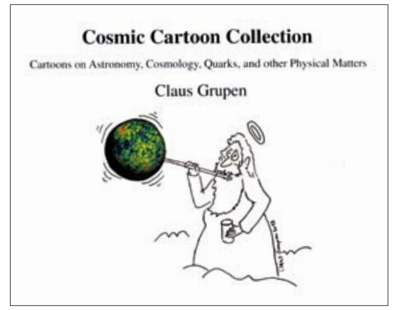
I also hoped for a discussion of the relation of Henri Poincaré to Hendrik Antoon Lorentz and Albert Einstein. There is only one phrase, on page 212 at the end of the subsection on an "old quarrel" with Einstein – and in my view this is inaccurate. What I know from having read some of Poincaré's research papers is that it was Lorentz who was castigated by Poincaré for "needing five pages where five words suffice" (I paraphrase). The situation with Einstein seemed more complex. Here I was seeking clarity. Everybody "knows", and therefore in accord with diplomatic traditions, this book avoids any explicit mention of what is, in my opinion, the historical-context issue of importance.



A search on the web reveals a recommendation letter from Poincaré regarding the appointment of Einstein at ETH-Zurich written in November 1911 – see www.lettersofnote.com/2013/11/one-of-most-original-thinkers-i-have.html. In this letter, Poincaré the mathematician, who died in 1912, characterizes Einstein the young physicist, who became noticed around 1907–1912, as an oddity among scientists, deserving a mention for this reason: "Mr Einstein is one of the most original thinkers I have ever met," and going on to say, "Since he seeks in all directions one must…expect most of the trails which he pursues to be blind alleys." This shows that Poincaré died in ignorance of the fact that Einstein had already created several new paradigms of science, of which (special) relativity was directly related to Poincaré's own work. I wonder if there is any other evidence in the press or in letters about what Poincaré knew and thought about Einstein?

Having seen this letter, I believe that in November 1911 Poincaré had no appreciation of the subtle nature of Einstein's revolutionary work. Poincaré, who worked on the generalized Lorentz transformations, does not mention $E = mc^2$, arguably the most famous equation, published six years previously. By 1911 Poincaré had created the tools that were needed to prove $E = mc^2$ in more abstract mathematical terms, and yet he showed no interest in following Einstein's footsteps. Why?

With the two pivotal issues – Henri Poincare's relation to the family's political



power and his competition with the young and most-important scientist of the epoch – not addressed, I wonder what priorities led to selection of the material that is presented. There is the "Dreyfus affair", which is discussed amply and where Poincaré played an honourable role. This was clearly of contemporary importance, but historically, looking at Poincaré the pre-eminent mathematician, this is a footnote at best. On the other hand, the presentation of his involvement in Ernst Mach's thinking and the Earth's rotation is the high point of this small book, and might yet justify its presence in the history of science literature.

● *Johann Rafelski, University of Arizona.*

Cosmic Cartoon Collection: Cartoons on Astronomy, Cosmology, Quarks, and other Physical Matters
By Claus Grupen
Universitätsverlag Siegen
Paperback: €5

Cartoons about science often take on a life of their own, as people copy them to add interest to their presentations, hand them on, add them to their websites, blogs and so on. I once found an excellent one about neutrinos left on a photocopier, which later became a key part of some of my talks. What often happens is that the name of the cartoonist becomes lost as the cartoons become widely spread – especially if the signature is small and becomes blurred with multiple copying. That seems to be the case with some of Claus Grupen's work. Indeed, I was recently asked to identify the source of a familiar cartoon about the Higgs boson. Only after failing to find the answer via Google, did I remember that Grupen draws cartoons – and, yes, it was one of his.

Probably better known as a physicist and author of a number of textbooks, for example, on astroparticle physics (*CERN Courier* January/February 2006 p54), he also has a talent for sketching, and so could create his own amusing visuals to accompany his lectures. He has now assembled a range of his output in this small book published by Siegen University, where he has been professor of

physics for many years.

As advertised in the subtitle, the cartoons cover a variety of topics in physics, but mainly focus on phenomena at the largest and smallest scales. Some are decidedly whimsical, while others are more didactic, and some seem to hark back to an earlier age in terms of the representation of women. This said, there is enough variety to bring a smile to most physicists, and at least now when people use one of Grupen's cartoons, they might know whom to credit.

● *Christine Sutton, CERN.*

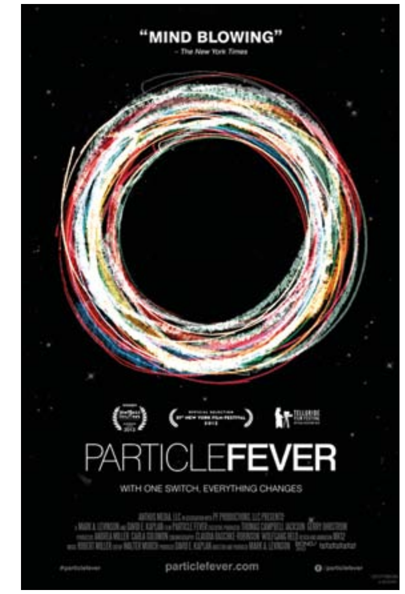
Film review

Particle Fever

"He was ALWAYS there!" This was the reaction of CERN scientists who spent years being followed by film-maker Mark Levinson. The result is *Particle Fever* – a feature-length documentary about CERN, which has been touring cinemas and festivals, reaching audiences far beyond particle physics. Why? Because Levinson manages to capture, through his narrative and character-driven piece, a compelling story of passion, disaster, loss and then triumph. It is not "boy meets girl", but scientists build accelerator, scientists lose accelerator (in the September 2008 incident), scientists get accelerator running again and find elusive particle – cue thunderous applause.

The film focuses on a handful of CERN characters, from the ATLAS experiment mainly: Fabiola Gianotti, Martin Aleksa and Monica Dunford, together with Mike Lamont from the accelerator side. While this skews the film away from the reality of thousands of collaborating physicists, it enables a picture to form through the eyes of these protagonists of passionate people working together towards a common goal. Levinson weaves in US-based theorists David Kaplan, Nima Arkani-Hamed and Savas Dimopoulos to stitch together a dramatic narrative of a mighty quest for the Higgs boson. In being swept along by the action, the audience is also taught a fair amount of physics with the help of beautifully designed graphics. My most memorable scene is the moment of the first LHC collisions, where Levinson's use of music and kaleidoscopic imagery leaves the audience captivated by the almost spiritual exaltation of this scientific achievement.

This US film-maker aiming at a US audience has, inevitably, made an American film, with gutsy postdoc Monica and self-assured theorists. A great deal of the film is dominated by American accents, so much so that I felt that the international spirit of CERN became somewhat neglected.



Nonetheless, Monica delivers a spectacular performance and was by far my favourite "character", with her candid pieces to camera and analogies: "The entire control room is like a group of six-year-olds whose birthday is next week…and there'll be cake."

There is something incredibly heart-warming about watching your place of work portrayed dramatically on the big screen. Goosebumps came in waves with the film's twists and turns, and I came away thinking "Wow, I work there." As a result, I pity my poor family, who will all have to watch this at Christmas, whether they want to or not!

● *Kate Kahle, CERN.*

● *Particle Fever* is currently touring cinemas and festivals, and is available to buy as an HD download worldwide from 15 July. For more details, see http://particlefever.com/.

Books received

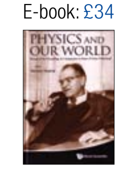
Symmetry and Fundamental Physics: Tom Kibble at 80
By Jerome Gauntlett (ed.)
World Scientific
Hardback: £38
Paperback: £18
E-book: £14

Tom Kibble – recently knighted (p36) – is an inspirational theoretical physicist who has made profound contributions to the understanding of the physical world. This book is a compilation of papers based on the presentations given at a symposium held in March 2013 at the Blackett Laboratory, Imperial College London, to celebrate his 80th birthday. The symposium profiled various aspects of his long scientific career, with talks from Neil Turok, Wojciech Zurek and Jim Virdee, and in the evening, Steven Weinberg and Frank Close.

Microcosmos: The World of Elementary Particles. Fictional Discussions between Einstein, Newton, and Gell-Mann
By Harald Fritzsch
World Scientific
Hardback: £18
Also available at the CERN bookshop

Suitable for non-experts in physics, this book provides a broad introduction to the field of particle physics through fictional discussions between three prominent physicists — Albert Einstein, Isaac Newton, and Murray Gell-Mann — together with a modern physicist. Matter is composed of quarks and electrons. By following these discussions, the reader should acquire an overview of the current status of particle physics and come to understand why particle physics is an exciting field.

Physics and Our World
Reissue of the Proceedings of a Symposium in Honor of Victor F Weisskopf
By Kerson Huang (ed.)
World Scientific
Hardback: £45
E-book: £34



As the proceedings of a symposium that took place in 1974 in honour of Victor Weisskopf — the well-known theoretician, who was CERN's fifth director-general during the years 1961–1966 — this volume contains papers by leaders of physics at the time, including Max Delbrück, Murray Gell-Mann, Hans Bethe, Tsung-Dao Lee, Ben Roy Mottelson, Wolfgang K H Panofsky, Edward Purcell, Julian Schwinger, Stanisław M Ulam and others.

While some of the papers address problems in the philosophy of physics and in physics and society that are timeless in nature, the symposium has a further significance. It took place at a historic juncture of particle physics – the emergence of the Standard Model as the result of experiments that pointed to the existence of quarks. Some of the papers reflect both the pre-quark and post-quark points of view. For these reasons, these proceedings merit reissue and re-examination.

Viewpoint

The strength of worldwide collaboration

Physicists from across the globe bring a welcome richness to the LHC experiments.

The enthusiasm and motivation to explore particle physics at the high-energy frontier knows no borders between the nations and regions of the planet. It is shared between physicists of widely different cultures and origins. This is evident today when looking around the large but still overcrowded auditoria where the latest results from the LHC are presented, as with the announcements of the Higgs-boson discovery (*CERN Courier* September 2012 p43). Such results are, in turn, presented by speakers on behalf of LHC collaborations that span the globe, with physicists from all inhabited continents.

Today we take this for granted, but it is worth remembering that it took about two decades to grow and consolidate these worldwide scientific and human projects into the peaceful, creative and efficient networks that are now exploring LHC physics. This process of collaboration building is of course not finished yet, and many challenges remain. CERN and its experiment collaborations at the LHC's predecessors – the Large Electron–Positron collider and the Super Proton Synchrotron $p\bar{p}$ collider – have long been a fertile cradle for physicists teaming up from different regions (*CERN Courier* March 2014 p23 and April 2014 p16), but with the LHC collaborations, globalization for the experiments has reached a new scale. Roughly speaking, about half of the participants in ATLAS and CMS are from non-member states of CERN.

I consider it a big privilege to have witnessed this evolution from inside CERN and actively from inside the ATLAS collaboration – and to have been able, humbly, to contribute to it a little. For me, the first contacts with far-away countries started with several visits as a junior member of CERN delegations in the late 1980s and early 1990s, presenting the LHC dream to colleagues and decision makers in places

Peter Jenni in the ATLAS cavern. (Image credit: Claudia Marcelloni.)

such as Russia (still the Soviet Union in the beginning), Eastern Europe and Japan, and later across the world. My "hat" changed quickly from predominantly CERN to ATLAS from the early 1990s, and the focus moved from generic LHC detectors and physics to a concrete experiment project.

A formidable evolution took place during the past 25 years, which was a pleasure to see. Presenting the LHC and ATLAS in the early years could be quite an adventure. There were places where electricity for the slides was not always guaranteed, many colleagues from potential new collaboration partners barely spoke any English, and the local custom could be that only the most senior professor would be expected to speak up. Today one may find, at the same places, the most modern conference installations and – even more enjoyable to see – confident, clever young students and postdocs expressing their curiosity and opinions.

What was also striking in the early times was the great motivation to be part of the experiment collaborations and to contribute – sometimes under difficult conditions – to the building up of the experiments. I often had the impression that colleagues in less privileged countries made extraordinary efforts, with many personal sacrifices, to fulfil their promises for the construction of the detectors. Those of us from richer countries should not forget that!

Of course an experiment like ATLAS could not have been built without the massive and leading contributions from CERN's member states and other large, highly industrialized countries, and we experimentalists must be grateful for their support in the first place. They are the backbone that made it possible to be open to other countries that have great human talent but little in the way of material resources.

The years immediately following the ATLAS and CMS Letters of Intent in October 1992 were a time when the two collaborations grew most rapidly in terms of people and institutes (*CERN Courier* June 2013 p22). The spokespersons made many trips to far-flung, non-European countries to motivate and invite participation and contributions to the experiments, in parallel (and sometimes even in competition) with CERN's effort to enlist non-member-state contributions to enable the timely construction of the accelerator. It was during this period that the current healthy mix of wealthy and less-wealthy countries was established in the two collaborations, placing value clearly not only on material contributions but also on intellectual ones.

The building up and consolidation of collaboration with continents in the Southern hemisphere is, in general, more recent, and has benefited, for example in the case of Latin America, from European Union exchange programmes, which in particular have brought many bright students to the experiments (*CERN Courier* June 2014 p58). Yet, there is a long way to go in Africa, with many talented people eager to join the great LHC adventure. Of course fundamental physics is our mission, but personally I am also convinced that attracting young people into science will help society in all regions, ultimately. So CERN with the LHC, which from the early dreams now spans half of the organization's 60 years, can also be proud of contributing a seed to building up a peaceful global society. For me personally, besides the physics, the LHC has also brought many friends across the world.

● *Peter Jenni, Albert-Ludwigs-University Freiburg and CERN, spokesperson for ATLAS until February 2009.*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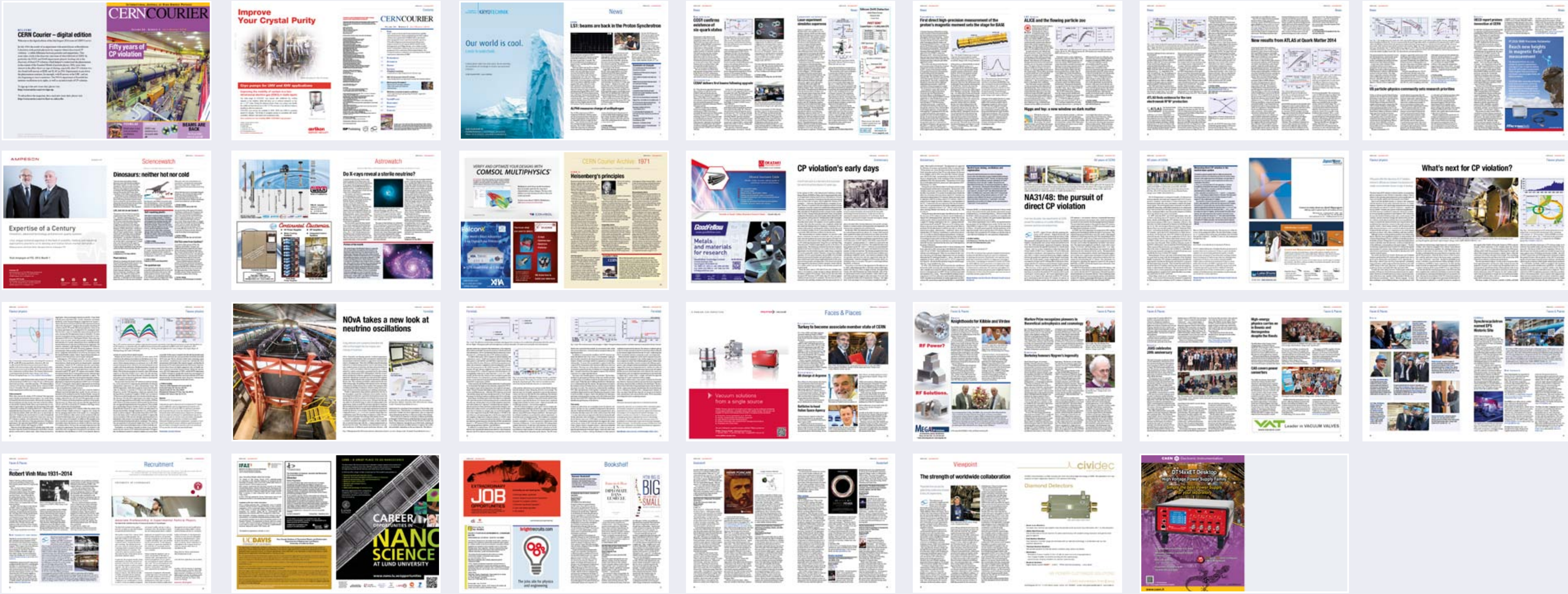

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