**WELCOME**

# CERN Courier – digital edition

Welcome to the digital edition of the May 2013 issue of *CERN Courier*.

Last July, the ATLAS and CMS collaborations announced the discovery of a new particle at the LHC with a mass of 125 GeV. They referred to it as a "Higgs-like boson" because further data were needed to pin down more of its properties. Now, the collaborations have amassed enough evidence to identify the new particle as a Higgs boson, although the question remains of whether it is precisely the Higgs boson of the Standard Model of particle physics. The discovery brings the final touches to a picture that came into focus 30 years ago, when experiments at CERN first observed the W and Z bosons. The masses of these particles were just as electroweak theory predicted, based on their interactions with a hypothesized Higgs field and its boson. Meanwhile, other particle interactions continue to provide puzzles in more complex systems, from relatively simple nuclei to the hot, dense fireball created in heavy-ion collisions.

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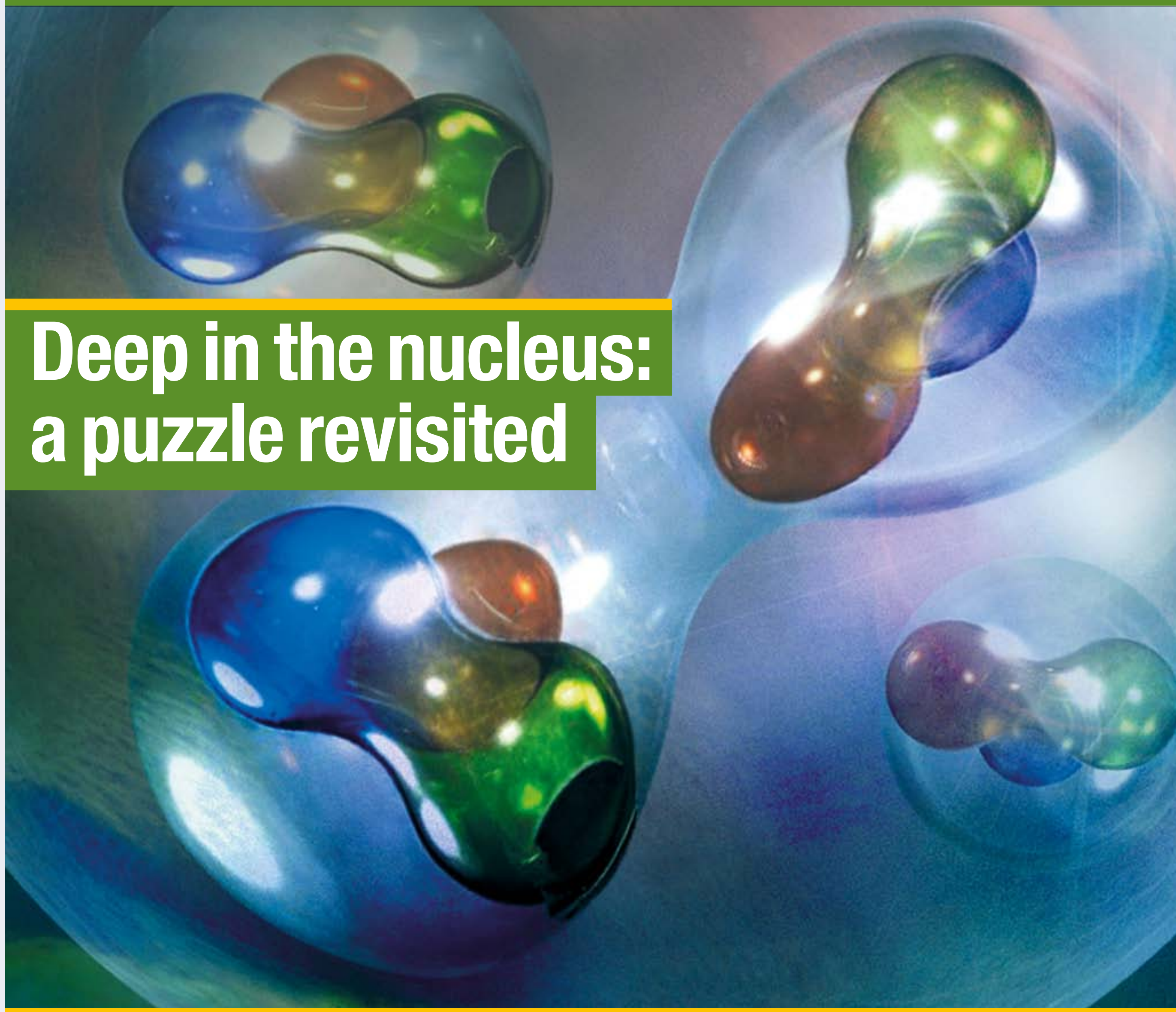

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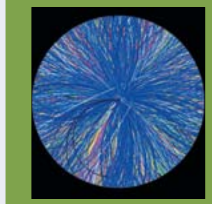

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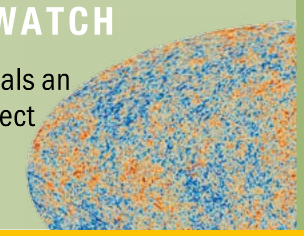

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**Covering current developments in high-energy physics and related fields worldwide**

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**On the cover:** An artist's depiction of nucleons being distorted in the nuclear medium as they come close together. Recent experiments are casting new light on the EMC effect, discovered 30 years ago at CERN (p35). (Image credit: Jefferson lab.)





# News

ASTROPARTICLE PHYSICS

## AMS measures antimatter excess in space

The international team running the Alpha Magnetic Spectrometer (AMS) has announced the first results in its search for dark matter. They indicate the observation of an excess of positrons in the cosmic-ray flux. The results were presented by Samuel Ting, the spokesperson of AMS, in a seminar at CERN on 3 April, the date of publication in *Physical Review Letters*.

*Perched on the International Space Station around 400 km above the Earth, the Alpha Magnetic Spectrometer (AMS) collects data from primary cosmic rays before they can interact with the atmosphere. (Image credit: NASA.)*

The AMS results are based on an analysis of some $2.5 \times 10^{10}$ events, recorded over a year and a half. Cuts to reject protons, as well as electrons and positrons produced in the interactions of cosmic rays in the Earth's atmosphere, reduce this to around $6.8 \times 10^6$ positron and electron events, including 400,000 positrons with energies between 0.5 GeV and 350 GeV. This represents the largest collection of antimatter particles detected in space.

The data reveal that the fraction of positrons increases from 10 GeV to 250 GeV, with the slope of the increase reducing by an order of magnitude over the range 20–250 GeV. The data also show no significant variation over time, or any preferred incoming direction. These results are consistent with the positrons' origin in the annihilation of dark-matter particles in space but they are not yet sufficiently conclusive to rule out other explanations.

The AMS detector is operated by a large international collaboration led by Nobel laureate Samuel Ting. The collaboration involves some 600 researchers from China, Denmark, Finland, France, Germany, Italy, Korea, Mexico, the Netherlands, Portugal, Spain, Switzerland, Taiwan and the US. The detector was assembled at CERN, tested at ESA's ESTEC centre in the Netherlands and launched into space on 16 May 2011 on board NASA's Space Shuttle *Endeavour* (*CERN Courier* July/August 2011 p18). Designed to study cosmic rays before they interact with the Earth's atmosphere, the experiment is installed on the International Space Station. It tracks incoming charged particles such as protons and electrons, as well as antimatter particles such as positrons, mapping the flux of cosmic rays with unprecedented precision.

An excess of antimatter within the cosmic-ray flux was first observed around two decades ago in experiments flown on high-altitude balloons and has since been seen by the PAMELA detector in space and the Large Area Telescope on the Fermi Gamma-ray Space Telescope (CERN Courier May 2009 p12 and June 2009 p17). The origin of the excess, however, remains unexplained.

One possibility, predicted by theories involving supersymmetry, is that positrons could be produced when two particles of dark matter collide and annihilate. Assuming an isotropic distribution of dark-matter particles, these theories predict the observations made by AMS. However, the measurement by AMS does not yet rule out the alternative explanation that the positrons originate from pulsars distributed around the galactic plane (*CERN Courier* September 2009 p16). Moreover, supersymmetry theories also predict a cut-off at higher energies above the mass range of dark-matter particles and this has not yet been observed.

AMS is the first experiment to measure to 1% accuracy in space – a level of precision that should allow it to discover whether the positron observation has an origin in dark matter or in pulsars. The experiment will further refine the measurement's precision over the coming years and clarify the behaviour of the positron fraction at energies above 250 GeV.

**Further reading**

M Aguilar *et al.* AMS collaboration 2013 *Phys. Rev. Lett.* **110** 141102.

### Sommaire en français



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

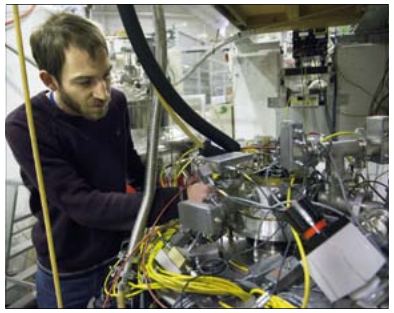
**CERN Courier welcomes contributions** from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

ANTIPARTICLES

# ATRAP makes world's most precise measurement of antiproton magnetic moment

The Antihydrogen TRAP (ATRAP) experiment at CERN's Antiproton Decelerator has reported a new measurement of the antiproton's magnetic moment made with an unprecedented uncertainty of 4.4 parts per million (ppm) – a result that is 680 times more precise than previous measurements. The unusual increase in precision results from the experiment's ability to trap individual protons and antiprotons, as well as from using a large magnetic gradient to gain sensitivity to the tiny magnetic moment.

By applying its single particle approach to the study of antiprotons, the ATRAP experiment has been able make precise measurements of the charge, mass and magnetic moment of the antiproton. Using a Penning trap, the antiproton is suspended at the centre of an iron ring-electrode that is sandwiched between copper electrodes. Thermal contact with liquid helium keeps the electrodes at 4.2 K, providing a nearly perfect vacuum that eliminates the stray matter atoms that could otherwise annihilate the antiproton. Static and oscillating voltages applied to the electrodes allow the antiproton to be manipulated and its properties to be measured.



*Stephan Ettenauer with the Penning trap apparatus that allows measurements of single antiprotons in the ATRAP experiment.*

The result is part of an attempt to understand the matter–antimatter imbalance of the universe. In particular, a comparison of the antiproton's magnetic moment with that of the proton, tests the Standard Model and its CPT theorem at high precision. The ATRAP team found that the magnetic moments of the antiproton and proton are "exactly opposite": equal in strength but opposite in direction with respect to the particle spins and consistent with the prediction of the Standard Model and the CPT theorem to 5 parts per million.

However, the potential for much greater measurement precision puts ATRAP in position to test the Standard Model prediction much more stringently. Combining the single particle methods with new quantum methods that make it possible to observe individual antiproton spin flips should make it feasible to compare an antiproton and a proton to 1 part per billion or better.

**● Further reading**

J DiSciacca *et al.* 2013 *Phys. Rev. Lett.* **110** 130801.

LHC PHYSICS

# Precision measurements of $B^0_s$ mesons put the squeeze on new physics

The "winter" conferences earlier this year saw the LHCb collaboration present three important results from its increasingly precise search for new physics.

One fascinating area of study is the quantum-mechanical process in which neutral mesons such as the $D^0$, $B^0$ and $B^0_s$ can oscillate between their particle and antiparticle states. The $B^0_s$ mesons oscillate with by far the highest frequency of about $3\times10^{12}$ times per second, on average about nine times during their lifetime. In an updated study, the collaboration looked at the decays of $B^0_s$ mesons into $D^-_s\pi^+$ with $D^-_s$ decays reconstructed in five different channels. While the $B^0_s$ oscillation frequency $\Delta m_s$ has been measured before, the oscillations themselves had been previously seen only by folding the decay-time distribution onto itself at the period of the measured oscillation. In this updated analysis the oscillation pattern is spectacularly visible over the full decay-time distribution, as figure 1 shows. The measured value of the oscillation frequency is $\Delta m_s = 17.768 \pm 0.023 \pm 0.006\ \text{ps}^{-1}$, which is the most precise in the world (LHCb collaboration 2013a).

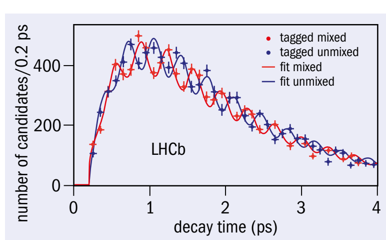
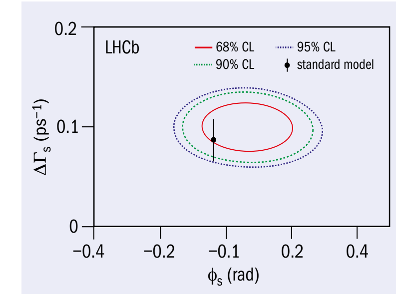



*Fig. 1. The decay-time distribution measured for $B^0_s$ oscillations.*

CP violation can occur in the $B^0_s$ sector – in the interference between the oscillation and decay of the meson – but it is expected to be a small effect in the Standard Model. Knowledge of such CP-violating parameters is important because they set the scale of the difference between properties of matter and antimatter; they may also reveal effects of physics beyond the Standard Model. LHCb has previously reported on a study of $B^0_s$ decays into $J/\psi\,\phi$ and $J/\psi\,\pi^+\pi^-$ final states, but now the analysis has been finalized. One important improvement is in the flavour tagging, which determines whether the initial state was produced as a $B^0_s$ or anti-$B^0_s$ meson. This decision was previously based on "opposite-side" tagging, i.e. from measuring the particle/antiparticle nature of the other b-quark produced in conjunction with the $B^0_s$. The collaboration has now achieved improved sensitivity by including "same-side" tagging, from the charge of a kaon produced close to the $B^0_s$, as a result of the anti-s-quark produced in conjunction with the $B^0_s$. This increases the statistical power of the tagging by about 40%. The values of the CP-violating parameter $\phi_s$, together with the difference in width of the heavy and light $B^0_s$ mass states, $\Delta\Gamma_s$, are shown in figure 2, which also indicates the small allowed region for these two parameters, corresponding to $\phi_s = 0.01 \pm 0.07 \pm 0.01$ rad and $\Delta\Gamma_s = 0.106 \pm 0.011 \pm 0.007\ \text{ps}^{-1}$ (LHCb collaboration 2013b)

Last, the collaboration has opened a door for important future measurements with a first study of the time-dependent CP-violating asymmetry in hadronic $B^0_s$ meson decays into a $\phi\phi$ pair, a process that is mediated by a so-called penguin diagram in the Standard Model. Both $\phi$ mesons decay in turn into a $K^+K^-$ pair. The invariant mass spectrum of the four-kaon final state shows a clean signal of about 880 $B^0_s\to\phi\phi$ decays. A first measurement of the CP-violating phase $\phi_s$ for this decay indicates that it lies in the interval of (–2.46, –0.76) rad at 68% confidence level. This is consistent with the small value predicted in the Standard Model, at the level of 16% probability. Although the current precision is limited, this will become a very interesting measurement with the increased statistics from further data taking (LHCb collaboration 2013c)




*Two-dimensional profile likelihood in the ($\Delta\Gamma_s$, $\phi_s$) plane showing the small allowed region for the two parameters.*

These results represent the most precise measurements to date, based on data corresponding to the 1 fb$^{-1}$ of integrated luminosity that LHCb collected in 2011. They are in agreement with the Standard Model predictions and significantly reduces the parameter region in which the signs of new physics can still hide.

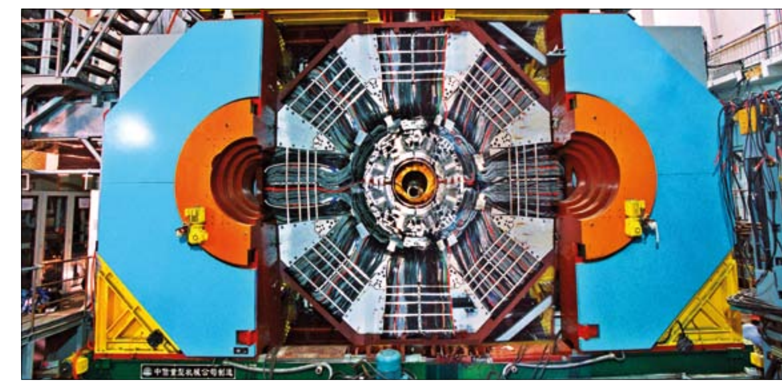
**● Further reading**

LHCb collaboration 2013a CERN-PH-EP-2013-054.
LHCb collaboration 2013b CERN-PH-EP-2013-055.
LHCb collaboration 2013c arXiv:1303.7125, submitted to *Phys. Rev. Lett.*

BEPC

# BESIII observes new mystery particle

In a striking and unexpected observation from new studies aimed at an understanding of the anomalous Y(4260) particle, the international team that operates the Beijing Spectrometer (BESIII) experiment at the Beijing Electron–Positron Collider (BEPCII) has reported that it decays to a new, and perhaps even more mysterious, particle that they have named the $Z_c(3900)$.



*The BESIII spectrometer. (Image credit: BESIII/IHEP.)*

The Y(4260) has mystified researchers since its discovery by the BaBar collaboration at SLAC in 2005. While other particles with certain similarities have long been successfully explained as bound states of a charmed quark and anticharmed quark, attempts to incorporate the Y(4260) into this model have failed and its underlying nature remains unknown. In December 2012, the BESIII team embarked on a programme to produce large numbers of Y(4260) particles by annihilating electrons and positrons with a total energy tuned to the particle's mass. Previous studies had used electron–positron collisions at a higher energy, where the Y(4260) mesons were produced via the relatively rare process in which either the original electron or positron particle first radiated a high-energy photon, thereby lowering the total annihilation energy to the mass region of the Y(4260). By contrast, by tuning the beam energies to the particle's mass, BEPCII can produce the Y(4260) directly and more efficiently. During the first two weeks of the programme, BESIII already collected the world's largest sample of Y(4260) decays and by the end of the first month there was strong evidence pointing to the existence of the $Z_c(3900)$.

The anomalous charmonium particles – such as the Y(4260) and, now, the $Z_c(3900)$ – appear to be members of a new class of recently discovered particles. Called the XYZ mesons, they are adding new dimensions to the study of the strong force. QCD, the theory of the strong force, allows more possibilities for charmonium mesons than simply a charmed quark bound to an anticharmed quark. One possibility is that gluons may exist inside mesons in an excited state, a configuration referred to as "hybrid charmonium". An alternative is that more than just a charmed and anticharmed quark may be bound together to form a "tetraquark" or a molecule-like meson.

Some progress has been made recently in using lattice QCD to account for the existence of the Y(4260) as a state of hybrid charmonium. However, the hybrid picture cannot explain the newly discovered $Z_c(3900)$, which decays into a charged pion plus a neutral $J/\psi$. To decay in this way, the $Z_c(3900)$ must contain a charmed quark and an anticharmed quark (to form the $J/\psi$) together with something that is charged, so therefore cannot be a gluon. To have nonzero charge, the $Z_c(3900)$ cannot be a hybrid, but must also contain lighter quarks. Different theoretical models have been proposed that attempt to explain how this could come about. The positively charged $Z_c(3900)$ particle could be a tightly bound four-quark composite of a charmed and anticharmed quark pair plus an additional up quark and antidown quark. Or, perhaps, the $Z_c(3900)$ is a molecule-like structure comprising two mesons, each of which contain a charmed quark (or anticharmed quark) bound to a lighter antiquark (or quark). Another scenario is that the $Z_c(3900)$ is an artefact of the interaction between these two mesons.

Whatever the explanation, the appearance of such an exotic state in the decay of another exotic state was not anticipated by most researchers. Now, the ball is clearly in the experimenters' courts and there is much hope – by theorists and experimenters alike – that with more data, the veil that continues to shroud these mysterious particles can be lifted.

- The Beijing Spectrometer (BESIII) collaboration has some 350 members from 50 institutions in 11 countries.

**Further reading**

BESIII collaboration 2013 arXiv:1303.5949 [hep-ex], submitted to *Phys. Rev. Letts.*

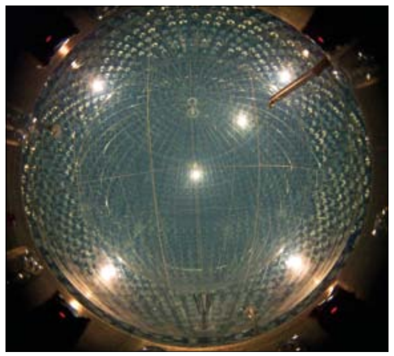
**GRAN SASSO**

# Borexino has new results on geoneutrinos

The international Borexino collaboration has released results from a new measurement of geoneutrinos corresponding to 1352.60 live days and about 187 tonnes of liquid scintillator after all selection criteria have been applied ($3.7 \times 10^{31}$ proton × year). This corresponds to a 2.4 times higher exposure with respect to the measurement made in 2010 (*CERN Courier* May 2010 p6).

Borexino is a liquid-scintillator detector built principally underground at INFN Gran Sasso National Laboratory in central Italy to detect solar neutrinos (*CERN Courier* June 2009 p13). However, because of its high level of radiopurity – unmatched elsewhere in the world – it can also detect rare events such as the interactions of geoneutrinos. These are electron-antineutrinos that are produced in the decays of long lived radioactive elements ($^{40}K$, $^{238}U$ and $^{232}Th$) in the Earth's interior.

From the data collected, 46 electron-antineutrino candidates have been found, about 30% of them geoneutrinos. Borexino has also detected electron-antineutrinos from nuclear power plants around the world. These latter antineutrinos give a signal of about 31 events, which is in good agreement with the number expected from the 446 nuclear cores operating during the period of interest (December 2007 to August 2012) and from current knowledge of the parameters of neutrino oscillations. The total expected background for electron-antineutrinos in Borexino is determined to be about 0.7 events. The small background is a result of the high level of radiopurity of the liquid scintillator. For the current measurement, the null geoneutrino hypothesis has a probability of $6 \times 10^{-6}$.



*A view inside the Borexino detector, after filling with scintillator was completed on 15 May 2007. (Image credit: Borexino collaboration.)*

The detection of geoneutrinos offers a unique tool to probe uranium and thorium abundances within the mantle (*CERN Courier* April 2011 p19). By considering the contribution from the local crust (around the Gran Sasso region) and the rest of the crust to the geoneutrino signal, the signal from the radioactivity of uranium and thorium in the mantle can be extracted. The latest results from Borexino, together with the measurement by the KamLAND experiment in Japan, indicate a signal from the mantle of 14.1±8.1 TNU (1 TNU = 1 event/year/$10^{32}$ protons).

These new results mark a breakthrough in the comprehension of the origin and thermal evolution of the Earth. The good agreement between the ratios of thorium to uranium determined from geoneutrino signals and the value obtained from chondritic meteorites has fundamental implications for cosmochemical models and the processes of planetary formation in the early Solar System.

By measuring the geoneutrino flux at the surface, the contribution of radioactive elements to the Earth's heat budget can be explored. The radiogenic heat is of great interest for understanding a number of geophysical processes, such as mantle convection and plate tectonics. For the first time two independent geoneutrino detectors – Borexino and KamLAND, which are placed in different sites around the planet – are providing the same constraints on the radiogenic heat power of the Earth set by the decays of uranium and thorium. With these latest results, the Borexino collaboration finds that the data fit to a possible georeactor with an upper limit on the output power of 4.5 TW at 95% confidence level.

**Further reading**

G Bellini *et al.* Borexino collaboration 2013 arXiv:1303.2571 [hep-ex].

# OPERA catches third τ neutrino

The OPERA experiment at Gran Sasso has observed a third neutrino oscillation, with a muon-neutrino produced at CERN detected as a τ neutrino in the Gran Sasso laboratory. This extremely rare event was observed only twice previously.

OPERA, which is run by an international experiment involving 140 physicists from 28 research institutes in 11 countries, was set up for the specific purpose of discovering neutrino oscillations of this kind. A beam of neutrinos produced at CERN travels towards the INFN Gran Sasso National Laboratory some 730 km away. Thanks to their weak interactions, the neutrinos arrive almost unperturbed at the giant OPERA detector, which consists of more than 4000 tonnes of material, has a volume of some 2000 $m^3$ and contains nine million photographic plates.

After the first neutrinos arrived at Gran Sasso in 2006, the experiment gathered data for five consecutive years, from 2008 to 2012. The first τ neutrino was observed in 2010, the second in 2012 (*CERN Courier* July/August 2010 p5 and July/August 2012 p7).

The arrival of the τ neutrino is an important confirmation of the two previous observations. Statistically, the observation of three τ neutrinos enables the collaboration to claim confidently that muon neutrinos oscillate to τ neutrinos. Data analysis is set to continue for another two years.

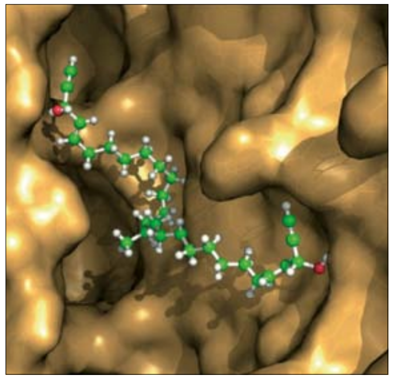
# Sciencewatch

Compiled by John Swain, Northeastern University

## Crystallography without crystals

X-ray single-crystal diffraction, or SCD, is a powerful tool for determining molecular structure but it requires crystals that are often difficult to grow and can require more material than is readily available for exotic compounds. Now, Makoto Fujita of the University of Tokyo and colleagues have found a clever way round these problems. They have used networked porous-metal complexes as a kind of "crystalline sponge" that can hold molecules in an ordered array without their having to form a real stand-alone crystal.

Crystallographic information of such a filled structure can then reveal both the host framework and the guest molecules.



*Orientation of miyakosyne A – extracted from a marine sponge species – in the pore of a crystalline sponge framework. The new method allowed the full characterization of this scarce natural product.*

The method seems to work amazingly well. Just 5 μg of a rare marine natural product (miyakosyne A) in a zinc-based crystalline sponge was enough for its structure to be determined. The approach should greatly speed up structural determinations for many substances.

**Further reading**
Y Inokuma *et al.* 2013 *Nature* **495** 461.

## Hydrogen from plants

While hydrogen might be a fuel of the future, it still has to come from somewhere – in splitting water, for example – and that requires energy. Now, Y-H Percival Zhang of Virginia Tech and colleagues have recently made a breakthrough in getting hydrogen from plant material. They take a variety of enzymes collected from micro-organisms that enjoy high temperatures and mix them with polyphosphate to convert xylose – a sugar that makes up 20–30% of plant matter by weight – into hydrogen with high yields.

The reaction is entropy-driven and runs at a modest 50° C, which could be provided by waste heat from other processes. So not only does the technique release the energy in the xylose, it also recovers energy from the heat used to drive the reaction – something that is not achieved in other processes that convert sugar into biofuels such as ethanol. This could be a breakthrough for hydrogen as a clean, renewable fuel that can be burnt without producing carbon dioxide.

**Further reading**
J S Martin del Campo *et al.* 2013 *Angewandte Chemie*, doi: 10.1002/ange.201300766.

## Caffeine and bees

While many of us are glad that some plants make caffeine, it is an interesting question to ask why these plants bother. The answer may at least partly be to help bees to remember better. Geraldine Wright of Newcastle University and colleagues have found that honeybees rewarded with caffeine, which occurs in the nectar of *Coffea* and *Citrus* species, were three times as likely to remember a learnt floral scent as bees that were given only sugar. The caffeine levels in nectar are low enough not to be repellently bitter but apparently high enough to be psychoactive and keep the bees coming back for more.

**Further reading**
G A Wright *et al.* 2013 *Science* **339** 1202.

*Caffeine in the nectar of citrus flowers like these seems to help bees remember better. (Image credit: Zts/reamstime.com.)*

## Nature's topological insulator

Predicted in 2005 and first made in the laboratory in 2008, topological insulators are exotic materials that conduct only along their surfaces, thanks to a spin-momentum coupling that stops electrons moving through the bulk. Now, Pascal Gehring of the Max-Planck-Institut für Festkörperforschung in Stuttgart and colleagues have found that Kawazulite – a mineral with approximate composition $Bi_2(Te,Se)_2(Se,S)$, discovered in the Kawazu mine in Japan – is a natural topological insulator. The samples studied came from a former gold mine in Jílové u Prahy in the Czech Republic. Remarkably, they have fewer defects than their artificial counterparts so it might be worth mining such materials rather than making them.

**Further reading**
P Gehring *et al.* 2013 *Nano Letters* **13** 1179.

## 3D without glasses

Three-dimensional displays ultimately have to work by getting slightly different images into the left and right eyes of a viewer. Traditional approaches use glasses with high-speed shutters or polarization, and in the old days of black and white, glasses with red and blue filters sent red images to one eye and blue to the other. But now, a new idea could eliminate glasses entirely. David Fattal and colleagues at the Hewlett-Packard Laboratories in Palo Alto have made a wide-angle, glasses-free 3D display using LEDs to produce wide-angle multiview images, which essentially show different views of a scene to the left and right eyes in a discretized analogue of how reflected light from a 3D object in real life goes differently into each eye. They are able to show animated 3D images to viewers over a zone of 90°, which could theoretically go up to 180° and seems suitable for mobile devices.

**Further reading**
D Fattal *et al.* 2013 *Nature* **495** 348.

# Astrowatch

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

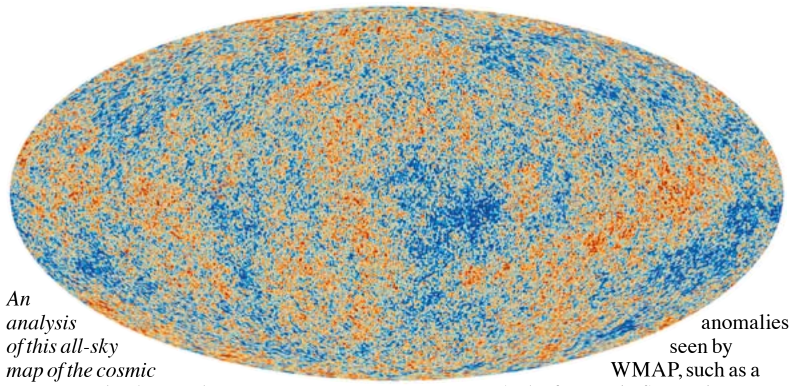
## Planck reveals an almost perfect universe

The long awaited results from ESA's Planck mission, based on the most detailed observations to date of the cosmic microwave background (CMB), were released on 21 March. While the new data confirm to high precision the standard model of cosmology, the detection of several anomalies could be hints of new physics to be understood.

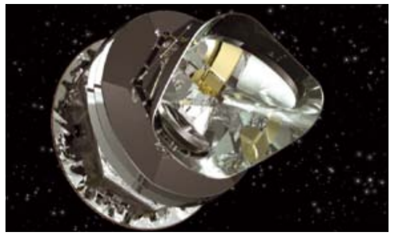
ESA's Planck and Herschel missions were launched simultaneously by an Ariane 5 rocket on 14 May 2009 (*CERN Courier* July/August 2009 p6). Since then, Planck has been scanning the whole sky every six months. After the results on galactic and extragalactic foregrounds (*CERN Courier* April 2012 p15), the Planck collaboration has now released the CMB results, the prime scientific objective of the mission. The collaboration issued almost 30 publications simultaneously, together with the data from the first half of the mission (15.5 months).

The CMB is a snapshot of the universe when it was 380,000 years old. At that time, the young universe was filled with a hot, dense medium of interacting protons, electrons and photons at about 2700° C. When the protons and electrons combined to form hydrogen atoms, radiation was set free. As the universe expanded, this radiation was stretched to microwave wavelengths, today equivalent to a temperature of just 2.7° C above absolute zero. The CMB is extremely uniform all over the sky. There are only tiny temperature fluctuations (at a level of $10^{-5}$) that correspond to regions of slightly different densities at very early times. Gravity will have acted to increase these fluctuations to form the galaxies and galaxy clusters that are seen today.

The fluctuations are of different amplitude on different angular scales. This is described by the power spectrum derived from the all-sky map of the CMB. The observed shape of the power spectrum can then be fitted by a model curve, whose shape is controlled by a set of cosmological parameters. There are only six free parameters for the standard model of a flat universe with cold dark matter and a cosmological constant, ΛCDM. Possible deviations from a pure ΛCDM cosmology can be tested by freeing additional parameters of the model. All attempts to search for deviations in the Planck data have proved insignificant. The main result of Planck is thus a remarkable confirmation of the standard ΛCDM model of the universe.



*An analysis of this all-sky map of the cosmic microwave background as measured by the Planck satellite allows the derivation of the fundamental cosmological parameters governing the history and the fate of the universe. Colours indicate slight differences in temperature. (Image credit: ESA and the Planck collaboration.)*



*The Planck spacecraft. (Image credit: ESA/Image by AOES Medialab.)*

Compared with NASA's Wilkinson Microwave Anisotropy Probe (WMAP) satellite, Planck has a much higher sensitivity, a smaller angular scale and a larger spectral coverage, with nine bands instead of five. Yet despite this, Planck has not been able to change fundamentally the view of the cosmos as derived by WMAP (*CERN Courier* May 2006 p12, May 2008 p8). The updated energy-density content of the present universe consists of slightly higher fractions of ordinary, baryonic matter (4.9% instead of 4.5%) and of dark matter (26.8% instead of 22.7%), compensated by a decrease in the fraction of dark energy (68.3% instead of 72.8%). Planck has also confirmed the existence of some large-scale anomalies seen by WMAP, such as a lack of power in fluctuations at large angular scales, a small asymmetry on both sides of the ecliptic plane and the WMAP cold spot (*CERN Courier* October 2007 p13). Planck shows that these anomalies are, indeed, of cosmic origin but they are at a level still marginally compatible (2–3σ) with statistical variations on the sky.

The main highlights of the Planck results are constraints on the number and mass of relativistic neutrinos ($N_{eff} = 3.30 \pm 0.27$ and $\Sigma m_\nu < 0.66$ eV), a strong constraint on any primordial non-Gaussianity ($f_{NL} = 2.7 \pm 5.8$) and constraints on inflation models ($n_s = 0.96 \pm 0.01$ and $r < 0.11$ at 95% CL). In addition to the CMB data, Planck is also releasing new catalogues of galaxy clusters and compact sources. This yields a potentially interesting tension between the amplitude of matter fluctuations derived from the CMB ($\sigma_8 = 0.82 \pm 0.02$) and from galaxy clusters ($\sigma_8 = 0.77 \pm 0.02$). Possibly the most unexpected result is a precise determination of the famous Hubble constant, which describes the rate of expansion of the universe, at a significantly lower value ($H_0 = 67.9 \pm 1.5$ km/s/Mpc) than derived by other means. This was one of the prime objectives of the Hubble Space Telescope; now it is Planck that makes the most precise determination so far. The next milestone for Planck will be in 2014 with the release of the final products for the complete mission, including the polarization measurements. There is still potential for more exotic discoveries.

**Further reading**

Planck collaboration 2013 arXiv: 1303.5062. [astron-ph.CO].

# CERN Courier Archive: 1970

A look back to CERN Courier vol. 8, May 1970, compiled by Peggie Rimmer

CERN

## The 300 GeV project

New proposals for the 300 GeV project were announced on 18 April. Here, we recap key headlines in its history.

**1963** The European Committee for Future Accelerators (ECFA) urges the construction in Europe of a new proton accelerator with an energy of about 300 GeV and high beam intensity.

**1964** A design study is carried out at CERN, with the major parameters: a peak energy of 300 GeV, a beam intensity of $10^{13}$ protons per second, a main-ring diameter of 2.4 km, "combined-function" magnets with a peak field of 12 kG, several ejected beams, design and construction time of 10 years, cost 1902 million Swiss francs (MSF) [1969 prices].

**1965** At the end of the year the CERN Council approves other ECFA recommendations in connection with the installations at CERN-Meyrin. These consist of an extensive improvement programme for the PS and its facilities, and the construction of intersecting storage rings for protons.

**1967** Approval is received in the US for an accelerator in the hundreds of GeV region. Design studies begin under the direction of R R Wilson for a 200 GeV machine with a potential for 500 GeV.

**1968** In June the UK government announces that it will not join the 300 GeV project. The project is revised to bring the cost down to 1431 MSF. Six countries declare their willingness to participate – Austria, Belgium, Federal Republic of Germany, France, Italy and Switzerland – thereby assuring sufficient funding.

**1969** The CERN Council accepts the development of the 300 GeV Laboratory in stages, beginning with an energy not less than 200 GeV and a construction period of eight years.

J B Adams, Director of the 300 GeV project, initiates a rethink that leads to a "missing magnet" design and a programme beginning with a 250 GeV machine, within the same budget, with conventional magnets taking up half of the circumference of a 3 km diameter ring. Filling up the circumference later would give 500 GeV. If superconducting magnets are mastered, there is the alternative of inserting them in the free half of the circumference to give 650 GeV, and eventually filling the ring with superconducting magnets to give 1300 GeV.

*The Director of the 300 GeV project, J B Adams, visited several US Laboratories in April. Here he is seen boarding a helicopter for an aerial view of the progress of construction of the 200–500 GeV accelerator at Batavia. With him, on the right, is F T Cole, Assistant Director for Technical Affairs. (Photo NAL.)*

This proposal, Project A, could be built on any of the five sites offered by States ready to participate (Doberdo-Italy, Drensteinfurt-Federal Republic of Germany, Focant-Belgium, Gopfritz-Austria, Le Luc-France). The problem of site selection, however, brought the project to a standstill at the end of the year, and in this situation, during the first months of 1970, Project B was born.

Project B attempted to come more into line with the finance which might reasonably be anticipated in the future, where past growth rates of expenditure on high-energy physics are unlikely to be sustained. It features a main ring about 2 km in diameter and a missing magnet design giving 300 GeV energy, with all magnets in place at a peak field of 18 kG. The cost of a 150 GeV stage, with half of the magnets, would be 1100 MSF with a construction time of eight years.

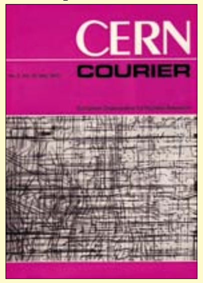
A significant aspect is that such a machine could be built not only on any of the five sites offered but also adjoining the existing Laboratory at CERN-Meyrin with further savings in cost and manpower. With the new accelerator next door, the existing CERN PS could, at least initially, serve as injector, eliminating the Booster from the construction programme, and the first experimental area for physics could be the existing PS West Hall. By the time of first high-energy beams this Hall will be exceptionally well equipped, including the 3.7 m European hydrogen bubble chamber and the "Omega project" for counter physics.

The exciting thing about this modification of Project B is that it opens up the possibility of physics at higher energies by the beginning of 1976 (if the project can go ahead in 1971) rather than several years later.

The discussion is continuing but already much has crystallized out. It is recognized that it is of supreme importance to move quickly if particle physics in Europe is to retain in the coming decades the excellent standing it has now.

● Compiled from texts on pp146–147.

### Compiler's Note



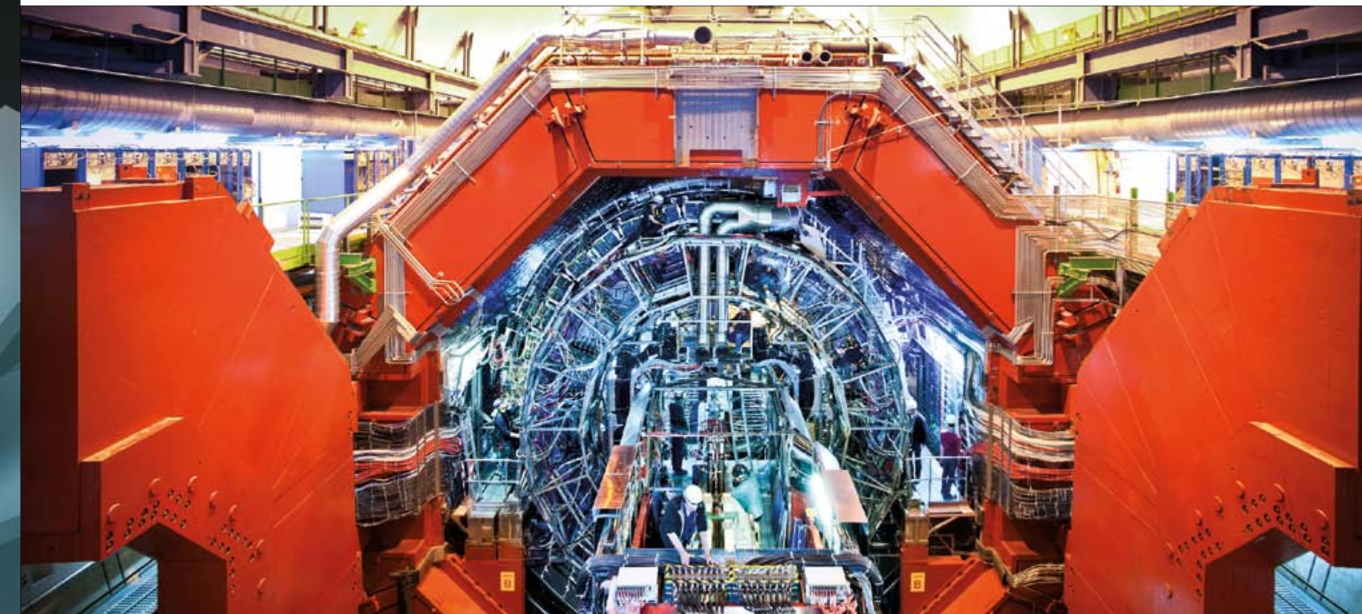

The machines being designed in 1970 to deliver external beams were later transformed into colliders, to exploit the huge gain in centre-of-mass energy when particle beams crash head-on.

CERN's 300 GeV project, the Super Proton Synchrotron (SPS), did indeed start operation in 1976 and at 400 GeV. But by 1981 it had become a collider, providing proton–antiproton collisions at 540 GeV and by 1983 the W and Z vector bosons of the weak force had been discovered (p27).

The Main Ring in what became Fermilab, Batavia, had already delivered 400 GeV protons by the end of 1972 and the bottom quark was discovered there in 1977. Revamped into the Tevatron, proton–antiproton collisions were produced at 1.6 TeV in 1985 and 1.8 TeV in 1986, and the discovery of the most massive quark, the top, was announced in 1995.

At CERN, the PS and the SPS are now in the injector chain of the Large Hadron Collider, where physics runs began in 2010 with two 3.5 TeV proton beams. Already a Higgs particle is in sight (p21). With spin 0, this scalar boson will be something different, neither matter nor force …



*The ALICE experiment with the solenoid magnet doors (in red) wide open, showing the interior of ALICE filled with detectors, pipes, tubes and cables – as well as people at work. (Image credit: Antonio Saba/ALICE.)*

# ALICE looks to the future

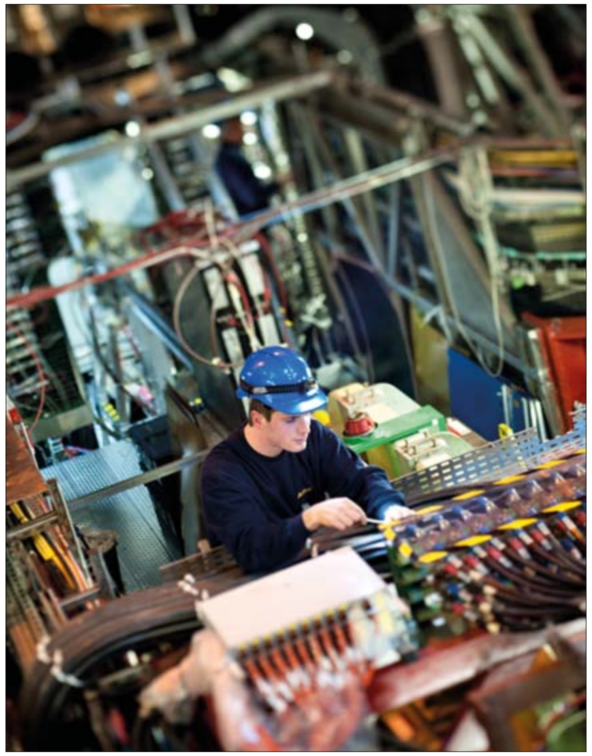
With the long shutdown under way, the ALICE collaboration is preparing for the next 10 years of operation.

After more than three years of highly successful operation, the ALICE detector is about to undergo a major programme of consolidation and upgrade during the Long Shutdown 1 (LS1) of CERN's accelerator complex. This follows an intense first running period characterized by the continuous record-breaking performance of the LHC. While the shutdown provides time to take stock of the wealth of data collected, the ongoing analysis, the busy programme of work in the experiment's cavern at Point 2 and the planning for future upgrades will ensure that everyone in the collaboration is kept busy.

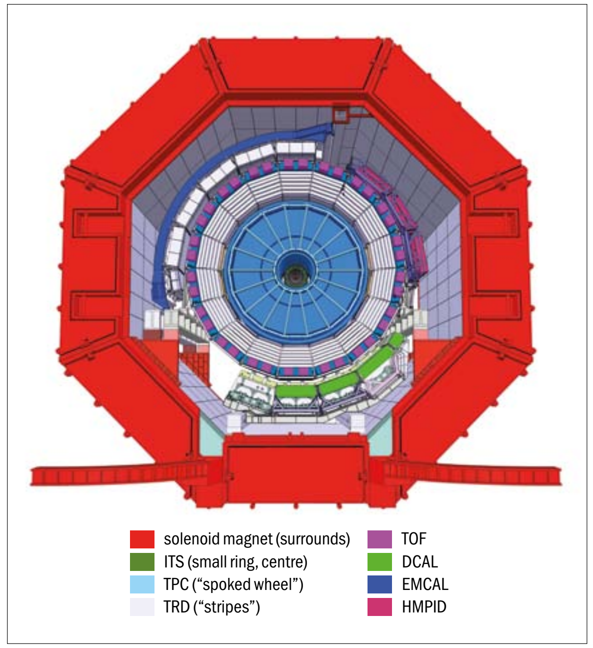
The ALICE detector is specially designed for heavy-ion collisions, which are foreseen as part of the LHC programme for four weeks a year. The LHC delivered an integrated lead–lead luminosity of $150\ \mu b^{-1}$ during heavy-ion periods in 2010 and 2011, as well $30\ nb^{-1}$ of proton–lead luminosity in 2013. Together with data collected during normal proton–proton running, as well as in a dedicated five-day proton–proton run in 2011 at the equivalent lead-nucleon energy, these three data sets have provided an excellent basis for an in-depth look at the physics of quark–gluon plasma. With the recent successful conclusion of the proton–lead programme in particular, where the LHC and injectors once again showed their amazing capabilities, the physics-analysis teams in ALICE are certainly not on standby but are more active and excited than ever.

## Down the cavern

As soon as LHC beam operations ended on 14 February, the occupation of the car park at the ALICE experimental site began to rise sharply, indicating the start of the major shutdown activities. (Long-term observations have shown that there is good proportionality between the number of parked cars and activities in the cavern.) The first of these, as in any ALICE shutdown, concerns the removal of hundreds of tonnes of shielding blocks from the access shaft and the cavern. This is to allow the opening of the large doors of the solenoid magnet and give access to the ALICE detector. This sequence is now well established because even during the short winter stops of 2010/2011 and 2011/2012, the ALICE detector ▷



*The consolidation of services, which includes air ducts, water ducts, high- and low-voltage power cables, optical fibres etc., will be one of the major activities during LS1. (Image credit: Antonio Saba/ALICE.)*




*Schematic view of the ALICE subdetectors inside the solenoid magnet. The dijet calorimeter (DCAL), which is being installed during LS1, is an extension to the electromagnetic calorimeter (EMCAL) that will increase azimuthal acceptance.*

was opened for installation of the electromagnetic calorimeter (EMCAL) and modules of the transition radiation tracker (TRD).

So what are the major plans for ALICE during LS1? The main activity on the detector will be concerned with the installation of the dijet calorimeter (DCAL), an extension of the existing EMCAL system that adds 60° of azimuthal acceptance opposite the existing 120° of the EMCAL's acceptance. This new subdetector will be installed on the bottom of the solenoid magnet, which currently houses three modules of the photon spectrometer (PHOS). An entirely new rail system and cradle will be installed to support the three PHOS modules and eight DCAL modules, which together weigh more than 100 tonnes.

The removal of the present structures and the installation of the new services, support structures and then the DCAL and PHOS modules will take up most of this year. The installation of five modules of the TRD will follow and so complete this complex detector system, which consists of 18 units. This work is complicated by the installation path being obstructed by major support-structures for services that will have to be temporarily supported by different structures.

In addition to these mainstream detector activities, all of the 18 ALICE subdetectors will undergo major improvements and consolidation efforts during LS1. The computers and discs of the online systems have reached their end of life and will also have to be replaced, followed by upgrades of the operating systems and online software.

A major part – indeed, most – of the shutdown cost and human resources will go into the consolidation and upgrade of the ALICE infrastructure. The four levels of ALICE counting rooms, which house the data-acquisition, high-level trigger, detector control-system and most of the detector read-out electronics, have an electrical infrastructure that was installed during the times of the Large-Electron–Positron collider and is now outdated. The renewal of this infrastructure and the installation of a new and significantly more powerful uninterruptible power-supply system form a key element in ensuring the correct operation of ALICE after LS1.



Major safety systems will also have to be installed during LS1. An area of racks under the large dipole magnet, which is inaccessible in the event of a fire, will be equipped with a $CO_2$ extinguishing system and the entire volume inside the solenoid magnet will be equipped with a nitrogen extinguishing system.

The production of chilled water will also undergo a major upgrade as a result of increased demands on cooling and ventilation for ALICE and the LHC. The need for doubling the cooling air-flow inside the solenoid magnet to 10,000 $m^3/h$ requires the addition of a new ventilation machine and large ventilation ducts from the surface to the cavern.

The shutdown activities have all been formulated in work packages, analysed for safety aspects and scheduled in detail. In addition, the extraction of LHC magnets through the ALICE shaft, as well as a large number of visitor groups that will come to see the experiment, will pose a big challenge to day-to-day planning for LS1.

All of these efforts will ensure that ALICE is in good shape for the three-year LHC running period after LS1, when the collaboration looks forward to heavy-ion collisions at the top LHC energy of 5.5 TeV/nucleon at luminosities in excess of $10^{27}$ $Hz/cm^2$.

However, the LS1 efforts go beyond the hardware activities that are currently under way. The ALICE collaboration has plans for a major upgrade during the next long shutdown, LS2, currently scheduled for 2018. Then the entire silicon tracker will be replaced by a monolithic-pixel tracker system; the time-projection chamber will be upgraded with gaseous electron-multiplier (GEM) detectors for continuous read-out; and all of the other subdetectors and the online systems will prepare for a 100-fold increase in the number of events written to tape. With only five years to go before this major upgrade, the ALICE collaboration is also busy on this front, preparing technical design reports for submission later this year.

With a fantastic set of data already in hand, well prepared activities for LS1 underway and the prospect of a major upgrade during LS2, the ALICE collaboration is in good health and is pursuing with unwavering enthusiasm its exploration of the mysteries of the QCD phase transitions, in a scientific programme that will extend well into the next decade.

**Résumé**

*ALICE regarde vers le futur*

*Après plus de trois ans de fonctionnement très satisfaisant, le détecteur ALICE va être soumis à tout un programme de consolidation et d'amélioration à l'occasion du premier grand arrêt du complexe d'accélérateurs du CERN. Ce programme fait suite à une première période d'exploitation, très intense, où le LHC s'est illustré en battant continuellement de nouveaux records. L'arrêt permet d'avoir du temps pour traiter l'ensemble de données recueillies. Mais entre la poursuite de l'analyse, le programme de travail chargé dans la caverne de l'expérience et la planification de futures améliorations, les membres de la collaboration ont du pain sur la planche.*

**Werner Riegler**, CERN.

# Birth of a Higgs boson

Results from ATLAS and CMS now provide enough evidence to identify the new particle of 2012 as 'a Higgs boson'.

In the history of particle physics, July 2012 will feature prominently as the date when the ATLAS and CMS collaborations announced that they had discovered a new particle with a mass near 125 GeV in studies of proton–proton collisions at the LHC. The discovery followed just over a year of dedicated searches for the Higgs boson, the particle linked to the Brout-Englert-Higgs mechanism that endows elementary particles with mass. At this early stage, the phrase "Higgs-like boson" was the recognized shorthand for a boson whose properties were yet to be fully investigated (*CERN Courier* September 2012 p43 and p49). The outstanding performance of the LHC in the second half of 2012 delivered four times as much data at 8 TeV in the centre of mass as were used in the "discovery" analyses. Thus equipped, the experiments were able to present new results at the 2013 Rencontres de Moriond in March, giving the particle-physics community enough evidence to name this new boson "a Higgs boson".

At the Moriond meeting, in addition to a suite of final results from the experiments at Fermilab's Tevatron on the same subject, the ATLAS and CMS collaborations presented preliminary new results that further elucidate the nature of the particle discovered just eight months earlier. The collaborations find that the new particle is looking more and more like a Higgs boson. However, it remains an open question whether this is *the* Higgs boson of the Standard Model of particle physics, or one of several such bosons predicted in theories that go beyond the Standard Model. Finding the answer to this question will require more time and data.

This brief summary provides an update of the measurements of the properties of the newly discovered boson using, in most cases, the full proton–proton collision data sample recorded by the ATLAS and CMS experiments in 2011 and 2012 for the $H\rightarrow\gamma\gamma$, $H\rightarrow ZZ^{(*)}\rightarrow 4l$, $H\rightarrow WW^{(*)}\rightarrow l\nu l\nu$, $H\rightarrow\tau^+\tau^-$ and $H\rightarrow b\bar{b}$ channels, corresponding to integrated luminosities of up to 5 $fb^{-1}$ at $\sqrt{s}=7$ TeV and up to 21 $fb^{-1}$ at $\sqrt{s}=8$ TeV. In the intervening time, CMS and ATLAS have also developed searches for rarer decays – such as $H\rightarrow Z\gamma$ or $H\rightarrow\mu^+\mu^-$ – and for invisible or undetectable decays expected in theories beyond the Standard Model.

Whether or not the new particle is a Higgs boson is demonstrated by how it interacts with other particles, as well as by its own quantum properties. For example, a Higgs boson is postulated to have no spin and in the Standard Model its parity – a measure of how its mirror image behaves – should be positive. ATLAS and CMS have compared a number of alternative spin-parity ($J^P$) assignments for this particle and, in pairwise hypothesis tests, the hypothesis of zero spin and positive parity ($0^+$) is consistently favoured, as summarized in Table 1.

| Observed $CL_s$ compared with $J^P=0^+$ | | $0^-$ (gg) pseudo-scalar | $2^+_m$ (gg) minimal couplings | $2^+_m$ ($q\bar{q}$) minimal couplings | $1^-$ ($q\bar{q}$) exotic vector | $1^+$ ($q\bar{q}$) exotic pseudo-vector |
|---|---|---|---|---|---|---|
| $ZZ^{(*)}$ | ATLAS | 2.2% | 6.8% | 16.8% | 6.0% | 0.2% |
| | CMS | 0.16% | 1.5% | <0.1% | <0.1% | <0.1% |
| $WW^{(*)}$ | ATLAS | – | 5.1% | 1.1% | – | – |
| | CMS | – | 14% | – | – | – |
| $\gamma\gamma$ | ATLAS | – | 0.7% | 12.4% | – | – |

*Table 1. Summary of preliminary results of the hypothesis tests compared with the Standard Model hypothesis of no spin, positive parity ($J^P=0^+$). All alternatives are disfavoured using the $CL_s$ ratio of probabilities that takes into account how the observation relates to both the Standard Model and the alternative hypotheses.*

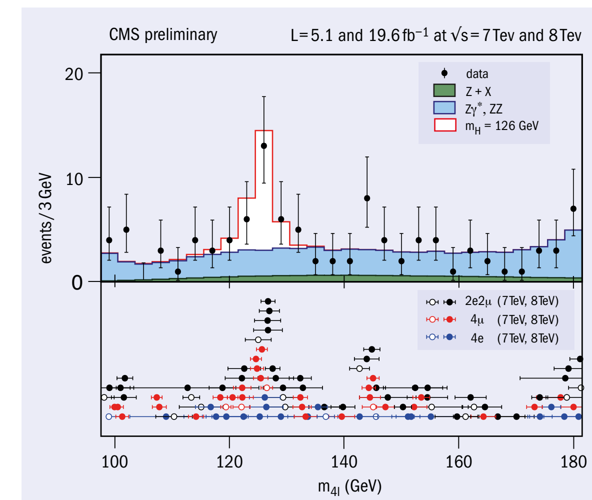



*Fig. 1. Distribution of the four-lepton events selected in the CMS analysis of $H\rightarrow ZZ^{(*)}\rightarrow 4l$. A clear accumulation of events is responsible for the excess 6.7σ above the background-only expectation at 125.8 GeV. Despite the large significance, the signal is $0.91^{+0.30}_{-0.24}$ times the expected amount for the Standard Model Higgs boson. The bottom panel provides further information on the individual events entering the analysis, including the final-state type and the per-event estimate of the mass and mass resolution.*

▷

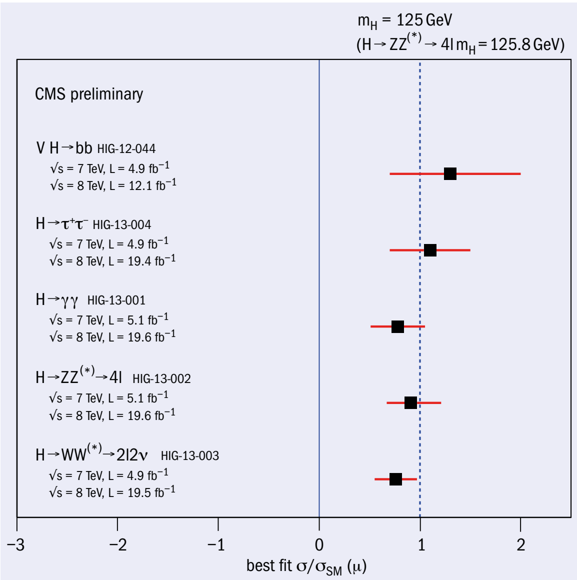



*Fig. 2. Summary of CMS measurements of the best-fit signal strength for the different Higgs-boson decay channels. Not only are all measurements more than 2σ away from zero (solid line), they are also all found to be in good agreement with the expectation for the Standard Model Higgs boson (dotted line).*

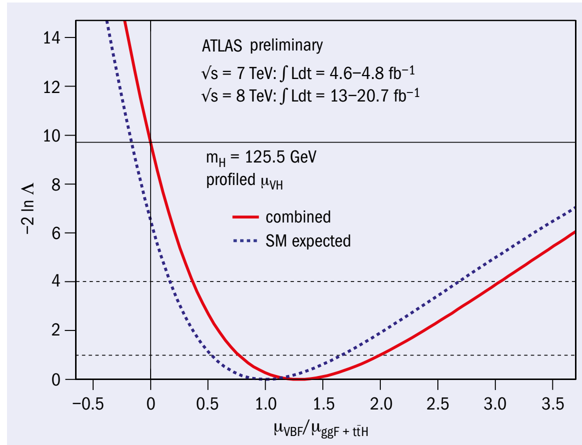



*Fig. 3. Likelihood scans of the ratio $\mu_{VBF}/\mu_{ggF+t\bar{t}H}$ for the combined $H\rightarrow\gamma\gamma$, $H\rightarrow ZZ^{(*)}\rightarrow 4l$, $H\rightarrow WW^{(*)}\rightarrow l\nu l\nu$ and $H\rightarrow\tau^+\tau^-$ channels for a hypothesis of a Higgs-boson mass of $m_H$=125.5 GeV. The branching ratios and possible non-Standard Model effects coming from the branching ratios cancel in $\mu_{VBF}/\mu_{ggF+t\bar{t}H}$, hence the different measurements from all four channels can be compared and combined. The dashed curve shows the Standard Model expectation for the combination. The horizontal dashed lines indicate the 1σ and 2σ confidence levels, with the horizontal full line indicating the confidence level corresponding to $\mu_{VBF}=0$.*

In CMS, the presence of a signal has been established in each of several expected decay channels. The $H\rightarrow\gamma\gamma$ and $H\rightarrow ZZ^{(*)}\rightarrow 4l$ channels point to a mass between 125.4 GeV and 125.8 GeV. For $m_H$ = 125 GeV, an excess of 4.1σ is observed in the $H\rightarrow WW^{(*)}\rightarrow l\nu l\nu$ channel and there are remarkable positive results in the decays to b quarks (2.2σ) and τ leptons (2.9σ), an important hint that this Higgs boson also couples to fermions. As expected in the Standard Model, the search for $H\rightarrow Z\gamma$ has not yielded a signal – nevertheless constraining the possibilities of models beyond the Standard Model.

Apart from exploiting the larger set of 8 TeV data, the CMS analyses have benefited from many improvements since the discovery announcement, from revised calibration constants to more sensitive analysis methods. In the $H\rightarrow\gamma\gamma$ and $H\rightarrow ZZ^{(*)}\rightarrow 4l$ channels, the largest difference is in the use of event classes with specific topologies to exploit the associated production modes. In these channels, the mass measurement has also benefited from improved energy and momentum resolution. Figure 1 (p21) shows the data entering the $H\rightarrow ZZ^{(*)}\rightarrow 4l$ analysis and it gives a sense of how individual events build up to a 6.7σ excess of events and how their mass resolution (also depicted) allows a measurement of the mass of the new boson at 125.8 ± 0.5(stat.) ± 0.2(syst.) GeV, the precision being dominated by statistics and already better than 0.5%. This mass measurement is in remarkable agreement with the value of 125.4 ± 0.5(stat.) ± 0.6(syst.) GeV measured in the $H\rightarrow\gamma\gamma$ channel, where the excess has a significance of 3.2σ. Updated CMS analysis of $H\rightarrow\gamma\gamma$, which takes advantage of the improved detector calibration, yields a result close to that expected for the Standard Model Higgs boson in terms of signal strength, $\mu=\sigma/\sigma_{SM}=0.78^{+0.28}_{-0.26}$.

In figure 2, an overview of the main decays studied in CMS shows how evidence for a Higgs boson can be seen in each channel with individual significances ranging from 2.2σ to 6.7σ. With respect to the results presented by CMS last July, there are slight differences in the individual signal strengths: smaller in the $H\rightarrow\gamma\gamma$ channel and larger in the $H\rightarrow b\bar{b}$ and $H\rightarrow\tau^+\tau^-$ channels. These results strongly indicate that it is a Higgs boson. Overall, the results continue to be fully compatible with the expectation for a Standard Model Higgs boson, while within the current uncertainties many scenarios of physics beyond the Standard Model are still allowed.

For ATLAS, the combined signal strength for $H\rightarrow\gamma\gamma$, $H\rightarrow ZZ^{(*)}\rightarrow 4l$, $H\rightarrow WW^{(*)}\rightarrow l\nu l\nu$ and $H\rightarrow\tau^+\tau^-$ has been determined to be $\mu$ = 1.30 ± 0.13(stat.) ± 0.14(syst) at the new mass measurement of 125.5 ± 0.2(stat.)$^{+0.5}_{-0.6}$(syst.) GeV. The collaboration has also measured the ratio of the cross-sections for vector-boson mediated and (predominantly) gluon-initiated processes for producing a Higgs boson, as shown in figure 3. Measurements of relative branching-fraction ratios between the $H\rightarrow\gamma\gamma$, $H\rightarrow ZZ^{(*)}\rightarrow 4l$ and $H\rightarrow WW^{(*)}\rightarrow l\nu l\nu$ channels, as well as combined fits testing the fermion and vector coupling sector, couplings to W and Z and loop-induced processes of the Higgs-like boson, show no significant deviation from the Standard Model expectation, as figure 4 shows.

Figure 3 compares a summary of the combined results for Higgs production to the Standard Model expectation and demonstrates an overall consistency. Here, a common signal-strength scale factor, ggF+tt̄H, has been assigned to the gluon-fusion (ggF) and the small tt̄H production mode because they both scale predominantly with the Yukawa coupling of the top quark in the Standard Model. For the combination, vector-boson-fusion-like events and gluon-fusion-like events are distinguished within the individual analyses based on the kinematic properties of the event. The combined measured ratio of production scaling factors, $\mu_{VBF}/\mu_{ggF+t\bar{t}H}=1.2^{+0.7}_{-0.5}$, driven by the $H\rightarrow\gamma\gamma$ channel measurement, gives more than 3σ evidence for Higgs-boson production through vector-boson fusion.





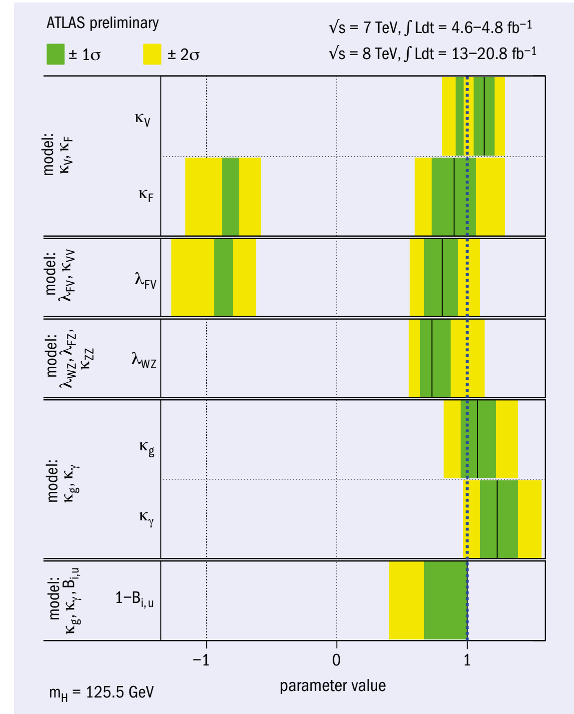



*Fig. 4. Summary of the coupling scale-factor measurements for $m_H$=125.5 GeV. The best-fit values are represented by the solid black vertical lines, while the Standard Model expectation is at +1. The results are typically consistent with the Standard Model, although when fermion couplings are involved, a sign ambiguity is not resolved. The measurements in the different coupling benchmark models are strongly correlated because they are obtained from fits to the same experimental data. In this figure, only a subset of the benchmark models is shown and for each one only the main parameters of interest are plotted.*

Having demonstrated overall consistency in terms of production, five tests of the observed coupling scale factors are summarized in figure 4. This shows the overall consistency with the Standard Model hypothesis and places limits on various model extensions for the produced Higgs boson. These tests are implemented according to recommendations from the Higgs Cross-Section Working Group. The ATLAS results assume a single, narrow CP-even Higgs resonance at $m_H$ = 125.5 GeV with coupling strengths that may depart from the Standard Model in various prescribed ways. For example, the relative vector boson and fermion coupling strengths (labelled $\kappa_V$, $\kappa_F$) are allowed to vary, giving the experimental constraints on the relative deviation of these quantities shown in the upper section of figure 4. The current results are not powerful enough to resolve the ambiguity in the relative sign of $\kappa_V$ and $\kappa_F$. Considering $\kappa_V > 0$, $\kappa_F$ has a double minimum leading to the observed structure in the intervals allowed by the data. Figure 4 also shows the results for other benchmark parameterizations where no assumption is made on the total width for the fermion-to-boson coupling-strength ratio (labelled $\lambda_{FV}$) and where the ratio of W-to-Z couplings is tested (labelled $\lambda_{WZ}$). Scenarios for physics beyond the Standard Model contributions via loops (labelled $\kappa_g$, $\kappa_\gamma$) and via invisible or undetectable decays (labelled $B_{i,u}$) can similarly be compared with the intervals allowed by the data.

After eight months, and thanks to the extraordinary performance of the LHC, the ATLAS and CMS collaborations have revealed more of the true nature of a new boson that is unique in the Standard Model. The more detailed picture that ATLAS and CMS have put together on this newborn boson since July 2012 remains unfailingly consistent with expectations drawn from the Standard Model, with the spin, parity, relative couplings, production and decay mechanisms all consistent at the current level of precision. Using the latest data, alternative hypotheses have been tested but none of them is found to be preferred over the Standard Model; rare decays have been searched for but, as expected in the Standard Model, no evidence for a signal has been found. The more similar this Higgs boson is to the Standard Model expectation, the more time, data and ingenuity will be required in the analyses of the LHC data to provide hints of physics at work beyond the Standard Model. Ultimately, upgraded and new accelerators will be needed to understand the interactions of the Higgs boson at a deeper level but for now it is clear that this boson is a precious thread with which we can hope to unravel more of the remaining mysteries of the universe.

## Further reading

For the presentations at Rencontres de Moriond, see http://moriond.in2p3.fr. For the latest preliminary Higgs results from ATLAS, see https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults, and for CMS, see https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG. For the Higgs Cross-Section Working Group pages, see https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections.

## Résumé

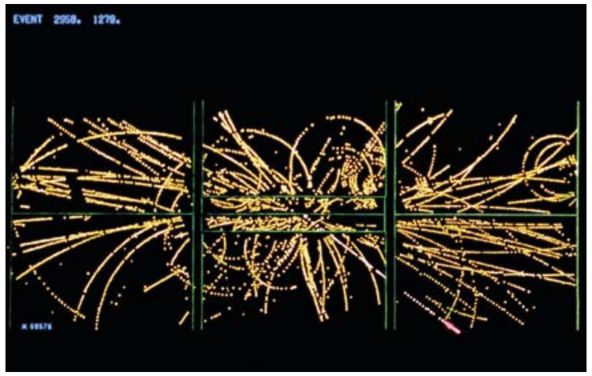
*Des résultats affinés : c'est un boson de Higgs*

*En juillet 2012, les collaborations ATLAS et CMS ont annoncé qu'elles avaient découvert une nouvelle particule ayant une masse d'environ 125 GeV. À ce stade, on utilisait l'expression « boson type Higgs » pour désigner cette particule, dont les propriétés restaient à étudier. Grâce à la performance remarquable du LHC, on a obtenu de la machine, au cours du second semestre 2012, quatre fois plus de données à 8 TeV que le volume utilisé dans les analyses ayant conduit à la découverte. Munies de toutes ces données, les expériences ont pu présenter de nouveaux résultats en mars 2013, et les éléments disponibles étaient suffisants pour qu'on puisse le dire : on a trouvé « un boson de Higgs ».*

The ATLAS and CMS collaborations.

# The scent of discovery: a visit to CERN in late 1982

**Lalit Sehgal** experienced an increased curiosity in electroweak physics at CERN in the weeks leading up to the discovery of the W and Z bosons.



*The discovery of the W particle in the UA1 detector in an event from the October–December 1982 run of the proton–antiproton collider. The W's decay produces a high transverse-energy electron (arrowed bottom right) back-to-back with missing energy, indicative of the emission of an invisible neutrino.*

In the autumn of 1982, I was invited to give a series of seven lectures at CERN under the title "Electroweak Interactions". These were part of the Academic Training Programme, which was aimed at young experimenters working on projects at CERN. The lectures were to be given on successive days on 18–26 November, excluding the weekend of 21–22 November. I had given seminars at CERN on earlier occasions and the response had always been positive. Giving seven lectures in a row could be stressful but at least the subject was in my own domain. I expected the number of people attending to be between 50 and 100.

When I arrived to give my lecture on the first day, I was astonished to see that the auditorium was chock-full of people. (Somebody mentioned later that the number was 400.) For a moment I thought that I had wandered into the wrong auditorium. Seated in the first row were stalwarts of CERN, such as Rolf Hagedorn, Jacques Prentki, Maurice Jacob and André Martin. I could see in the crowd several experienced people whom I knew from the heyday of neutrino physics. It was not at all the kind of audience that I had expected. I began to wonder what I could tell them that they had not heard a dozen times before.

### A bold venture

When the opening lecture ended I hastened to return to the dormitory to prepare my second talk. On the way I saw Jack Steinberger, one of the veterans of CERN, for whose course I had once acted as a tutor. I told him that I had come to CERN to give Academic Training lectures and he said, with dismay: "I know that. I looked for my people this morning and there was nobody around, because they had all gone to your lecture."

That evening I went to the CERN cafeteria for a coffee and there I saw something that I had not noticed before. There was a monitor on the wall and people were watching the screen with great interest. The monitor was showing the rate of proton–antiproton collisions in CERN's latest challenge – a bold venture designed to produce the intermediate bosons, W and Z. These bosons were predicted by electroweak theory to occur at masses of 80 GeV and 90 GeV, respectively. The synchrotron at CERN that accelerated protons to 400 GeV was, by itself, not capable of producing such massive particles. So CERN had built a smaller ring in which antiprotons produced in conventional proton interactions were accumulated. These antiprotons were compressed to compact beams, then accelerated to 270 GeV in the Super Proton Synchrotron and finally brought into head-on collision with 270 GeV protons. And this audacious idea appeared to be working! The collision rate was low but it was climbing from hour to hour. Now I understood the reason for the crowd in my lecture. CERN was on the way to testing the crucial prediction of electroweak theory, namely the existence of intermediate bosons with masses and properties that were precisely predicted. A confirmation of this prediction would be a triumph for CERN and would probably bring the laboratory its first Nobel prize.

**CERN was on the way to testing the crucial prediction of electroweak theory.**

I returned to my room in the dormitory and resumed the writing of my overhead transparencies. I now knew that my lectures would have to focus ▷

on precisely the questions that the physicists at CERN would be interested in: the cross-sections for W and Z production; the expected event rates; the angular distribution of the W and Z decay products, etc. People would also want to know how uncertain the predictions for the W and Z masses were and why certain theorists (J J Sakurai and James Bjorken among them) were cautioning that the masses could turn out to be different. The writing of the transparencies turned out to be time consuming. I had to make frequent revisions, trying to anticipate what questions might be asked. To make corrections on the film transparencies, I was using my after-shave lotion, so that the whole room was reeking of perfume. I was preparing the lectures on a day-by-day basis, not getting much sleep. To stay awake, I would go to the cafeteria for a coffee shortly before it closed. Thereafter I would keep going to the vending machines in the basement for chocolate – until the machines ran out of chocolate or I ran out of coins.

After the fourth lecture, the room in the dormitory had become such a mess (papers everywhere and the strong smell of after-shave) that I decided to ask the secretariat for an office where I could work. Office space in CERN is always scarce but they said I could use the office that was previously occupied by Sakurai. At that point I recalled, with sorrow, his tragic and totally unexpected death that I had read about some weeks earlier. I had forgotten that he was a visitor at CERN at the time. I had high regard for him as a physicist. There was a period of some years when we were doing parallel things in connection with the structure of neutral currents. He was always fair and correct in attributing credit and was an excellent lecturer. I had met him quite recently at the Neutrino '82 Conference in Balatonfüred and at the 1982 International Conference on High-Energy Physics in Paris. When the secretary opened the office for me, many of Sakurai's books and papers were still in the room. Lying on his desk were a couple of preprints that he had been reading on his last day at the office. I felt uncomfortable about disturbing that scene by bringing in my own papers and I told the secretary that I would continue to work in the dormitory.

### Champagne times

The lectures went well. The attendance declined after I had finished with the discussion of intermediate bosons (vector quanta) and Higgs particles (scalar quanta). On the eve of the last lecture, I went rather late to the CERN cafeteria for dinner. The place was almost deserted. I saw that there was one corner that had been screened off for a private get-together. There were sounds of a party, with clinking glasses and the pop of a champagne bottle. Glancing inside the screen, I saw Steinberger and a number of American visitors at CERN. I realised that it was Thursday and they were celebrating Thanksgiving. For a moment I had a desire to join them but my natural diffidence held me back. As I was about to leave, one person emerged from the enclosure. It was Gary Feldman from SLAC. He greeted me and said: " I have been attending your lectures. What are you going to talk about tomorrow?" When I said CP violation he said: "What a shame. I should have loved to hear that but I have to leave in the morning." He wished me luck.

Before leaving the cafeteria, I glanced at the monitor showing the status of the beams in the collider. The luminosity was still rising. The next morning, after my final lecture, I went over to the analysis room of the UA1 experiment in which physicists from Aachen were participating. They showed me a couple of events that were candidates for the W and Z. It seemed that CERN would have occasion to open champagne bottles, before too long.

*Less than 11 months after Lalit Sehgal's visit to CERN, Carlo Rubbia, left, and Simon van der Meer were awarded the 1984 Nobel prize for their roles in discovering the W and Z particles. It was Rubbia who pushed hard to bring about the conversion of CERN's SPS to a proton–antiproton collider, while van der Meer's technical insight made the project possible.*

I returned to Aachen quite exhausted. I resolved not to give so many lectures again (they had asked for only four/five). I also resolved not to use after-shave as a correcting fluid. But it had been a satisfying visit. I had come to CERN at a time full of suspense. There was a scent of discovery in the air.

On 25 January 1983, eight weeks after my return, CERN held a press conference to announce the discovery of the W boson. The announcement of the Z boson followed on 1 June

### Résumé

*Un parfum d'after-shave et de découverte : visite au CERN en novembre 1982*

*Quand Lalit Sehgal arriva au CERN pour donner une série de conférences sur la physique électrofaible, à l'automne 1982, il eut la surprise de découvrir un amphithéâtre bondé. Il devait rapidement comprendre pourquoi. Les expériences consacrées à la recherche des bosons W et Z avaient commencé, mettant à profit l'audacieuse conversion du Supersynchrotron à protons en collisionneur proton–antiproton. Il dut alors à plusieurs reprises passer la moitié de la nuit à adapter ses cours pour traiter en détail la production de ces bosons vecteurs. Avant son départ, les physiciens de l'expérience UA1 purent lui montrer quelques événements candidats et, en l'espace de quelques semaines, le boson W avait été découvert, suivi de peu par le Z.*

**Lalit M Sehgal**, Aachen.





# Finding the W and Z

Thirty years ago, CERN made scientific history with the discoveries of the W and Z bosons. Here, we reprint an extract from the special issue of *CERN Courier* that commemorated this breakthrough.

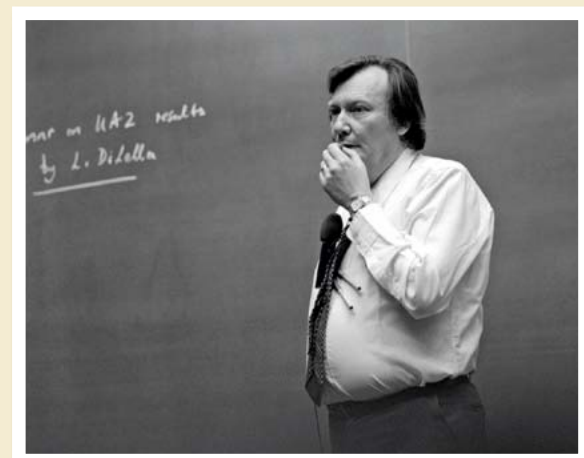
In February 1981, the Proton Synchrotron received and accelerated antiprotons from the Antiproton Accumulator, thus becoming the world's first Antiproton Synchrotron. On 7 July, transfer to the Super Proton Synchrotron, acceleration and brief storage at 270 GeV were achieved. Carlo Rubbia delayed his departure to the Lisbon High Energy Physics Conference by a day so that on 10 July he was able to announce that the UA1 detector had seen its first proton–antiproton collisions. There were runs at modest intensities in the second half of the year and the first visual records of the collisions came from another experiment (UA5) using large streamer chambers. UA5 was then moved out to make way for UA2, which took its first data in December.

In 1982, an accident to UA1 forced a concentration of the scheduled proton–antiproton running into a single two-month period at the end of the year (October to December). In terms of operating efficiency, it proved a blessing in disguise and research director Erwin Gabathuler happily sacrificed a crate of champagne to the machine-operating crews as the collision rate was taken to 10 times that of the year before. This was the historic run in which the W particles were first observed.

It was astonishing how fast physics results were pulled from the data accumulated up to 6 December 1982. At a Topical Workshop on Proton-Antiproton Collider Physics held in Rome from 12–14 January 1983, the first tentative evidence for observation of the W particle by the UA1 and UA2 collaborations was there. Out of the several thousand-million collisions that had been seen, a tiny handful gave signals that could correspond to the production of a W in the high-energy collision and its subsequent decay into an electron (or positron if the W was positively charged) and a neutrino. The detectors were programmed to look for high-energy electrons coming out at a relatively large angle to the beam direction. Also, energy imbalance of the particles around a decay indicated the emergence of a neutrino, which itself cannot be detected in the experimental apparatus.

The tension at CERN became electric, culminating in two brilliant seminars, from Carlo Rubbia (for UA1) on Thursday 20 January and Luigi Di Lella (for UA2) the following afternoon, both ▷

*On 3 July 1980, beam circulated for the first time in the Antiproton Accumulator (AA). At the centre are, left to right: Roy Billinge, with his hand on the control box, Eifionydd Jones and Simon van der Meer.*



*Carlo Rubbia presenting the discovery of the W boson by UA1 in a seminar at CERN on 20 January 1983.*



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with the CERN auditorium packed to the roof. UA1 announced six candidate W events; UA2 announced four. The presentations were still tentative and qualified. However, over the weekend of 22–23 January, Rubbia became more and more convinced. As he put it, "They look like Ws, they feel like Ws, they smell like Ws, they must be Ws". And, on 25 January, a press conference was called to announce the discovery of the W. The UA2 team reserved judgement at this stage but further analysis convinced them also. What was even more impressive was that both teams could already give estimates of mass in excellent agreement with the predictions (about 80 GeV) of the electroweak theory.

It was always clear that the Z would take longer to find. The theory estimated its production rate to be some 10 times lower than that of the Ws. It implied that the machine physicists had to push their collision rates still higher, and this they did in style in the second historic proton–antiproton run from April to July 1983. They exceeded by 50% the challenging goal that had been set and this time it was director-general Herwig Schopper who forfeited a crate of champagne.

Again there was tension as the run began because the Z did not seem keen to show itself. Although more difficult to produce than the W, its signature is easier to spot because it can decay into an electron–positron pair or a muon pair. Two such high-energy particles flying out in opposite directions were no problem for detectors and data-handling systems that had so cleverly unearthed the W.

On 4 May, when analysing the collisions recorded in the UA1 detector a few days earlier, on 30 April, the characteristic signal of two opposite high-energy tracks was seen. Herwig Schopper reported the event at the "Science for Peace" meeting in San Remo on 5 May. However, the event was not a clean example of a particle–antiparticle pair and it was only after three more events had turned up in the course of the month that CERN went public, announcing the discovery of the Z to the press on 1 June. Again, the mass (near 90 GeV) looked bang in line with theory. Just after the run, Pierre Darriulat was able to announce in July that UA2 had also seen at least four good Z decays.

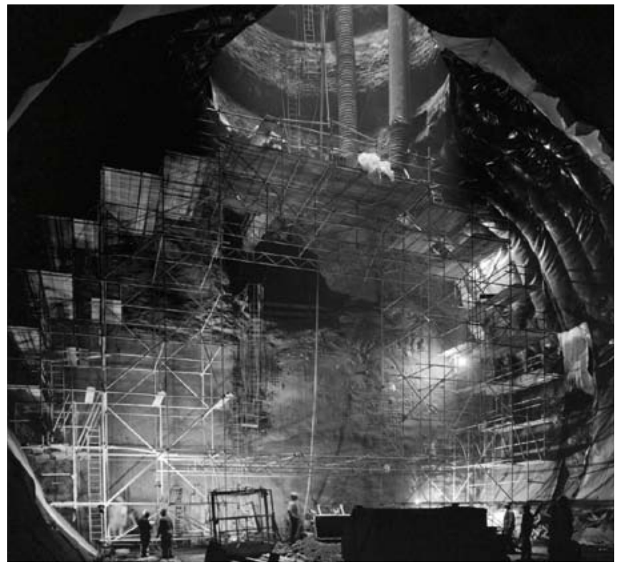
In addition to the Ws and Zs, the observed behaviour was everything that the electroweak theory predicted. Two independent experiments had confirmed a theory of breathtaking imagination and insight.

● Extracted from *CERN Courier* November 1982 pp360–361.

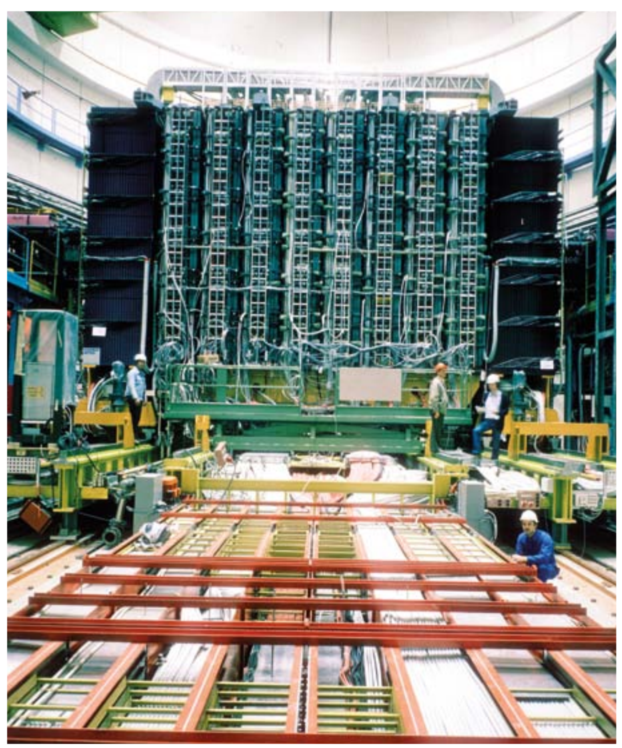
**Résumé**

*La découverte du W et du Z*

*Le Supersynchrotron à protons du CERN a commencé à fonctionner comme collisionneur proton–antiproton en juillet 1981. C'est lui qui a fourni les premières collisions pour l'expérience UA1, puis UA2. À l'automne 1982 a eu lieu l'exploitation au cours de laquelle les bosons W ont été observés pour la première fois. Cette découverte a été annoncée fin janvier 1983. Pour trouver le boson Z, il a fallu attendre la deuxième période d'exploitation, d'avril à juillet 1983, avec ses taux de collision plus élevés, et, le 1er juin, le CERN annonçait la découverte du Z. L'article reproduit ici est un court extrait d'un numéro spécial du Courrier CERN publié en novembre 1982.*

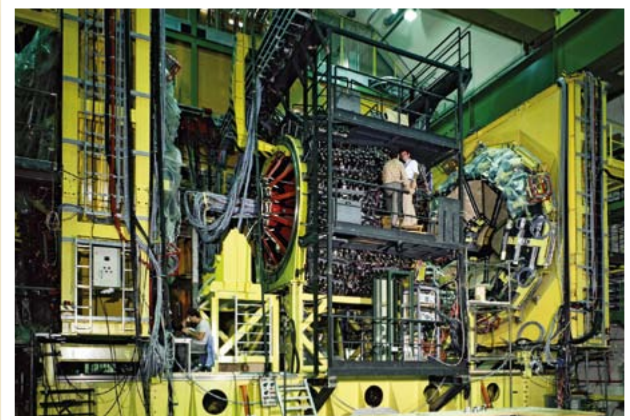


*Civil engineering for the underground experimental hall for UA2 in February 1980.*



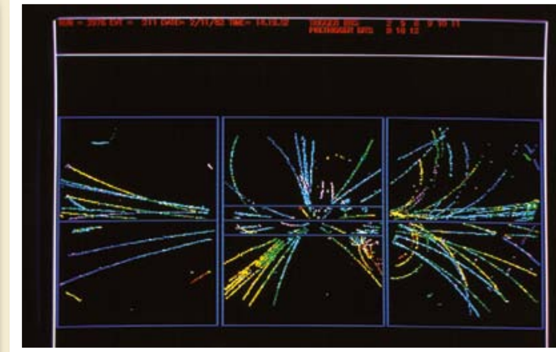
*The UA1 detector, shown here in its "garage" position, in April 1981.*

*The press conference at CERN on 25 January 1983, announcing the discovery of the W boson at CERN. From left to right: Carlo Rubbia, spokesperson of UA1; Simon van der Meer, responsible for developing the stochastic cooling technique; Herwig Schopper, director-general; Erwin Gabathuler, research director; and Pierre Darriulat, the UA2 spokesperson.*

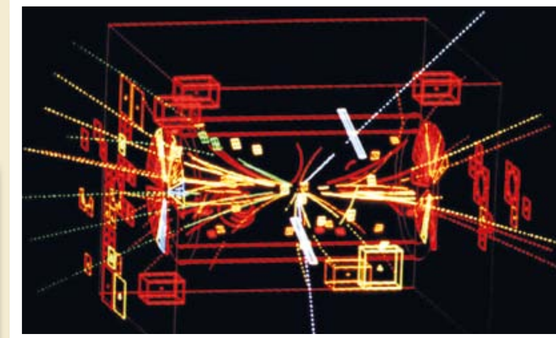


*The UA2 detector in September 1981.*

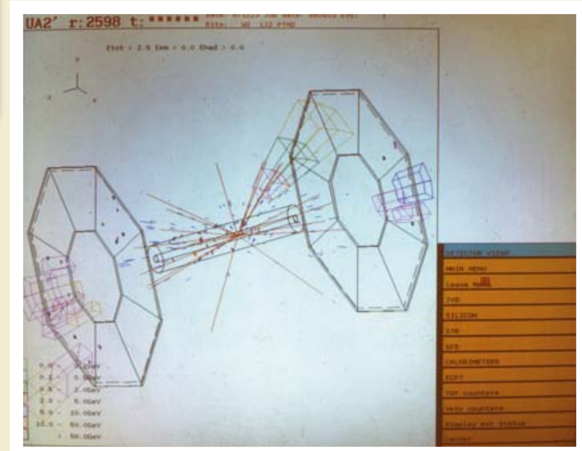
*Pierre Darriulat, spokesperson of UA2, in September 1983.*



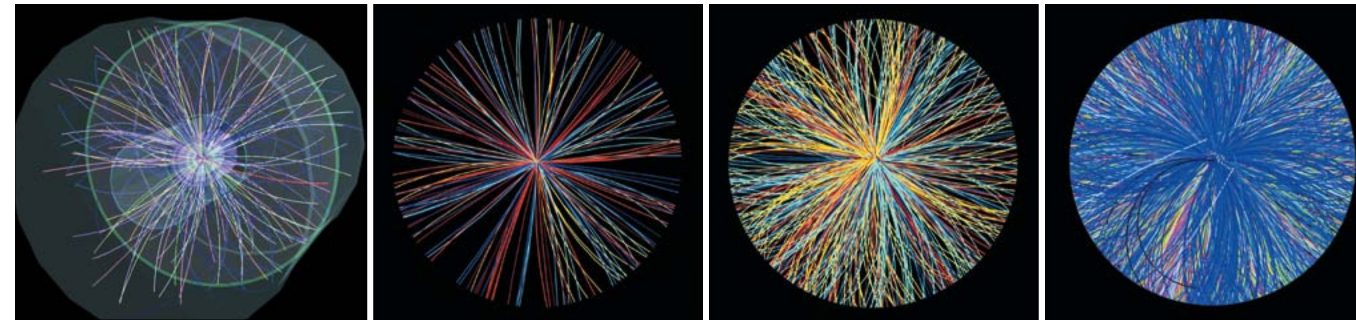
*An event in UA1 from the historic run in October to December 1982. The first W bosons were found during this run (see p25).*



*The first detection of a Z particle, recorded by the UA1 experiment on 30 April 1983. The two white tracks seen here reveal the electron–positron pair produced in the Z's decay.*



*A Z boson decaying to an electron–positron pair in the upgraded UA2 detector.*



*ALICE event displays going from most peripheral (left) to the most central (right) collisions. They show the track multiplicity in the time-projection chamber, transverse to the beam direction.*

# Participants and spectators at the heavy-ion fireball

To see how much of a heavy ion participates in a collision, ALICE must determine a key parameter – centrality.

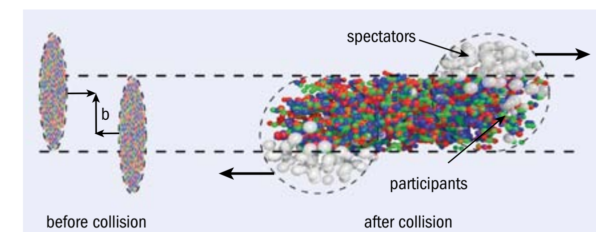



*Fig. 1. Left: Two heavy ions before collision with impact parameter b. Right: The spectator nucleons remain unaffected while particle production takes place in the participants' zone.*

Heavy-ion collisions are used at CERN and other laboratories to re-create conditions of high temperature and high energy density, similar to those that must have characterized the first instants of the universe, after the Big Bang. Yet heavy-ion collisions are not all equal. Because heavy ions are extended objects, the system created in a central head-on collision is different from that created in a peripheral collision, where the nuclei just graze each other. Measuring just how central such collisions are at the LHC is an important part of the studies by the ALICE experiment, which specializes in heavy-ion physics. The centrality determination provides a tool to compare ALICE measurements with those of other experiments and with theoretical calculations.

Centrality is a key parameter in the study of the properties of QCD matter at extreme temperature and energy density because it is related directly to the initial overlap region of the colliding nuclei. Geometrically, it is defined by the impact parameter, b – the distance between the centres of the two colliding nuclei in a plane transverse to the collision axis (figure 1). Centrality is thus related to the fraction of the geometrical cross-section that overlaps, which is proportional to $\pi b^2/\pi(2R_A)^2$, where $R_A$ is the nuclear radius. It is customary in heavy-ion physics to characterize the centrality of a collision in terms of the number of participants ($N_{part}$), i.e. the number of nucleons that undergo at least one collision, or in terms of the number of binary collisions among nucleons from the two nuclei ($N_{coll}$). The nucleons that do not participate in any collision – the spectators – essentially keep travelling undeflected, close to the beam direction.

However, neither the impact parameter nor the number of participants, spectators or nucleon–nucleon collisions are directly measurable. This means that experimental observables are needed that can be related to these geometrical quantities. One such observable is the multiplicity of the particles produced in collision in a given rapidity range around mid-rapidity; this multiplicity increases monotonically with the impact parameter. A second useful observable is the energy carried by the spectators close to the beam direction and deposited – in the case of the ALICE experiment – in the Zero Degree Calorimeter (ZDC); this decreases for more central collisions, as shown in the upper part of figure 2, overleaf.

Experimentally, centrality is expressed as a percentage of the total nuclear interaction cross-section, e.g. the 10% most central events are the 10% that have the highest particle multiplicity. ▷

But how much of the total nuclear cross-section is measured in ALICE? Are the events detected only hadronic processes or do they include something else?

ALICE collected data during the LHC's periods of lead–lead running in 2010 and 2011 using interaction triggers that have an efficiency large enough to explore the entire sample of hadronic collisions. However, because of the strong electromagnetic fields generated as the relativistic heavy ions graze each other the event sample is contaminated by background from electromagnetic processes, such as pair-production and photonuclear interactions. These processes, which are characterized by low-multiplicity events with soft (low-momentum) particles close to mid-rapidity, produce events that are similar to peripheral hadronic collisions and must be rejected to isolate hadronic interactions. Part of the contamination is rejected by requiring that both nuclei break-up in the collision, producing a coincident signal in both sides of the ZDC. The remaining contamination is estimated using events generated by a Monte Carlo simulator of electromagnetic processes (e.g. STARLIGHT). This shows that for about 90% of the hadronic cross-section, the purity of the event sample and the efficiency of the event selection is 100%. Nevertheless the most peripheral events, 10% of the total, remain contaminated by electromagnetic processes and trigger inefficiency – and must be used with special care in the physics analyses.

The centrality of each event in the sample of hadronic interactions can be classified by using the measured particle multiplicity and the spectator energy deposited in the ZDC. Various detectors in ALICE measure quantities that are proportional to the particle multiplicity, with different detectors covering different regions in pseudo-rapidity (η). Several of these, e.g. the time-projection chamber (covering $|\Delta\eta| < 0.8$), the silicon pixel detector ($|\Delta\eta| < 1.4$), the forward multiplicity detector ($1.7 < \Delta\eta < 5.0$ and $-3.4 < \Delta\eta < -1.7$) and the V0 scintillators ($2.8 < \Delta\eta < 5.1$ and $-3.7 < \Delta\eta < -1.7$), are used to study how the centrality resolution depends on the acceptance and other possible detector effects (saturation, energy cut-off etc.). The percentiles of the hadronic cross-section are determined for any value of measured particle multiplicity (or something proportional to it, e.g. the V0 amplitude) by integrating the measured distribution, which can be divided into classes by defining sharp cuts that correspond to well defined percentile intervals of the cross-section, as indicated in the lower part of figure 2 for the V0 detectors.

Alternatively, measuring the energy deposited in the ZDC by the spectator particles in principle allows direct access to the number of participants (all of the nucleons minus the spectators). However, some spectator nucleons are bound into light nuclear fragments that, with a charge-to-mass ratio similar to that of the beam, remain inside the beam-pipe and are therefore undetected by the ZDC. This effect becomes quantitatively important for peripheral events because they have a large number of spectators, so the ZDC cannot be used alone to give a reliable estimate of the number of participants. Consequently, the information from the ZDC needs to be correlated to another quantity that has a monotonic relation with the participants. The ALICE collaboration uses the energy of the secondary particles (essentially photons produced by pion decays) measured by two small electromagnetic calorimeters (ZEM). Centrality classes are defined by cuts on the two-dimensional dis-

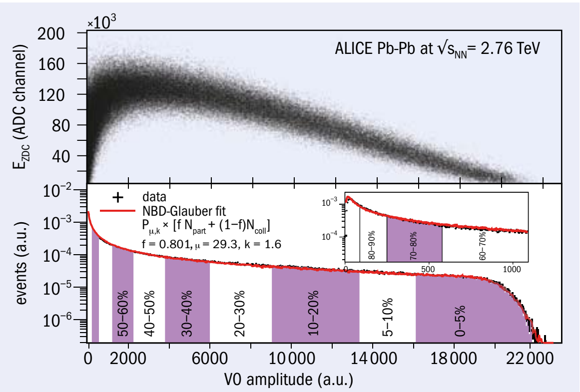



*Fig. 2. Top: Spectator energy deposited in the Zero-Degree Calorimeters (ZDC) as a function of amplitudes in the V0 scintillators. Bottom: Distribution of the sum of amplitudes in the V0 scintillators, indicating centrality classes. The NBD-Glauber fit is shown as a line. The inset shows an enlargement of the most peripheral region.*

tribution of the ZDC energy as a function of the ZEM amplitude for the most central events (0–30%) above the point where the correlation between the ZDC and ZEM inverts sign.

So how can the events be partitioned? Should the process be based on 0–1% or 0–10% classes? And what is the best way to estimate the centrality? These questions relate to the issue of centrality resolution. The number of centrality classes that can be defined is connected to the resolution achieved by the centrality estimation. In general, centrality classes are defined so that the separation between the central values of the participant distributions for two adjacent classes is significantly larger than the resolution for the variable used for the classification.

## The real resolution

In principle, the resolution is given by the difference between the true centrality and the value estimated using a given method. In reality, the true centrality is not known, so how can it be measured? ALICE tested its procedure on simulations using the event generator HIJING, which is widely used and tested on hadronic processes, together with a full-scale simulation of detector response based on the GEANT toolkit. In HIJING events, the value of the impact parameter for every given event and, hence, the true centrality is known. The full GEANT simulation yields the values of signals in the detectors for the given event, so using these centrality estimators an estimate of the centrality can be calculated. The real centrality resolution for the given event is equal to the difference between the measured and the true centrality.

In the real data we approximated the true centrality in an iterative procedure, evaluating event-by-event the average centrality measured by all estimators. The correlation between various estimators is excellent, resulting in a high centrality-resolution. Since the resolution depends on the rapidity coverage of the detector used, the best result – achieved with the V0 detector, which has the largest pseudo-rapidity coverage in ALICE – ranges from 0.5% in



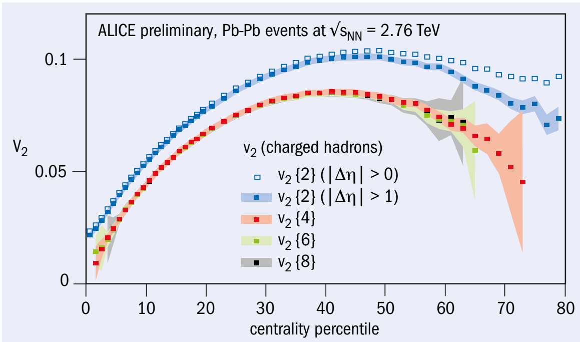



*Fig. 3. Elliptic flow measured as a function of centrality in centrality bins of 1%. The $v_2$ coefficient is extracted using two-particle correlations and the multi-particle cumulants (4th, 6th and 8th order).*

central collisions to 2% in peripheral ones, in agreement with the estimation from simulations. This high resolution is confirmed by the analysis of elliptic flow and two-particle correlations where the results, which address geometrical aspects of the collisions, change with 1% centrality bins (figure 3).

So much for the experimental classification of the events in percentiles of the hadronic cross-section. This leaves one issue remaining: how to relate the experimental observables (particle multiplicity, zero-degree energy) to the geometry of the collision (impact parameter, $N_{part}$, $N_{coll}$). What is the mean number of participants in the 10% most central events?

To answer this question requires a model. HIJING is not used in this case, because the simulated particle multiplicity does not agree with the measured one. Instead ALICE uses a much simpler model, the Glauber model. This is a simple technique, widely used in heavy-ion physics, from the Alternating Gradient Synchrotron at Brookhaven, to CERN's Super Proton Synchrotron, to Brookhaven's Relativistic Heavy-Ion Collider. It uses few assumptions to describe heavy-ion collisions and couple the collision geometry to the detector signals. First, the two colliding nuclei are described by a realistic distribution of nucleons inside the nucleus measured in electron-scattering experiments (the Woods-Saxon distribution). Second, the nucleons are assumed to follow straight trajectories. Third, two nucleons from different nuclei are assumed to collide if their distance is less than the distance corresponding to the inelastic nucleon–nucleon cross-section. Last, the same cross-section is used for all successive collisions. The model, which is implemented in a Monte Carlo calculation, takes random samples from a geometrical distribution of the impact parameter and for each collision determines $N_{part}$ and $N_{coll}$.

The Glauber model can be combined with a simple model for particle production to simulate a multiplicity distribution that is then compared with the experimental one. The particle production is simulated in two steps. Employing a simple parameterization, the number of participants and the number of collisions can be used to determine the number of "ancestors", i.e. independently emitting sources of particles. In the next step, each ancestor emits particles according to a negative binomial distribution (chosen because it describes particle multiplicity in nucleon–nucleon collisions). The simulated distribution describes up to 90% of the experimental one, as figure 2 shows.

Fitting the measured distribution (e.g. the V0 amplitude) with the distribution simulated using the Glauber model creates a connection between an experimental observable (the V0 amplitude) and the geometrical model of nuclear collisions employed in the model. Since the geometry information (b, $N_{part}$, $N_{coll}$) for the simulated distribution is known from the model, the geometrical properties for centrality classes defined by sharp cuts in the simulated multiplicity distribution can be calculated.

The high-quality results obtained in the determination of centrality are directly reflected in the analyses that ALICE performs to investigate the properties of the system that strongly depend on its geometry. Elliptic flow, for example, is a fundamental measurement of the degree of collectivity of the system at an early stage of its evolution since it directly reflects the initial spatial anisotropy, which is largest at the beginning of the evolution. The quality of the centrality determination allows access to the geometrical properties of the system with a very high precision. To remove non-flow effects, which are predominantly short-ranged in rapidity, as well as artefacts of track-splitting, two-particle correlations are calculated in 1% centrality bins with a one-unit gap in pseudo-rapidity. Using these correlations, as well as the multi-particle cumulants (4th, 6th and 8th order), ALICE can extract the elliptic flow-coefficient $v_2$ (figure 3), i.e. the second harmonic coefficient of the azimuthal Fourier decomposition of the momentum distribution (ALICE collaboration 2011). Such measurements have allowed ALICE to demonstrate that the hot and dense matter created in heavy-ion collisions at the LHC behaves like a fluid with almost zero viscosity (*CERN Courier* April 2011 p7) and to pursue further the hydrodynamic features of the quark–gluon plasma that is formed there.

## • Further reading

For more about centrality determination in ALICE see:
CERN-PH-EP-2012-368, arXiv:1301.4361 [nucl-ex].
ALICE collaboration 2011 *Phys. Rev. Lett.* **107** 032301.

## Résumé

*Participants et spectateurs dans les collisions d'ions lourds*

*Les collisions d'ions lourds sont utilisées pour recréer les conditions de haute température et de densité d'énergie qui doivent avoir existé aux tout premiers instants de l'Univers, après le Big Bang. Pourtant, toutes les collisions d'ions lourds ne sont pas égales. Comme les ions lourds sont des objets étendus, le système créé dans une collision centrale, frontale, est différent de celui qui résulte d'une collision périphérique, dans laquelle les noyaux ne font que s'effleurer. Mesurer la « centralité » des collisions au LHC constitue une partie importante des études réalisées par l'expérience ALICE, et fournit un outil permettant de comparer les mesures avec celles effectuées par les autres expériences, ainsi qu'avec les calculs théoriques.*

**Alberica Toia**, University of Padua/INFN.

# The EMC effect still puzzles after 30 years

Thirty years ago, high-energy muons at CERN revealed the first hints of an effect that puzzles experimentalists and theorists alike to this day.

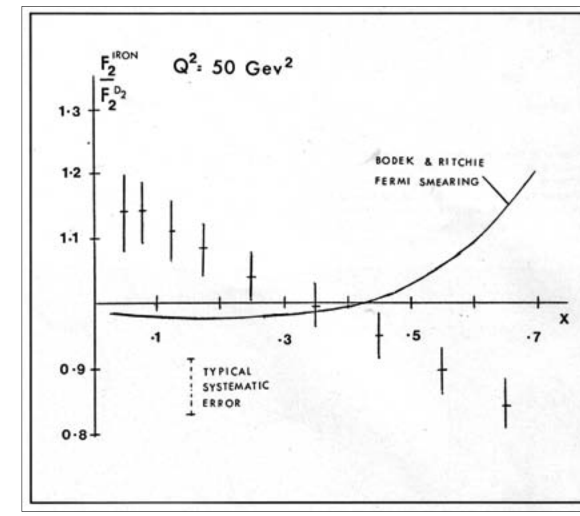



*Fig. 1. A plot of the EMC data as it appeared in the November 1982 issue of* CERN Courier. *This image nearly derailed the highly cited refereed publication (Aubert* et al. *1983) because the editor argued that the data had already been published.*

Contrary to the stereotype, advances in science are not typically about shouting "Eureka!". Instead, they are about results that make a researcher say, "That's strange". This is what happened 30 years ago when the European Muon collaboration (EMC) at CERN looked at the ratio of their data on per-nucleon deep-inelastic muon scattering off iron and compared it with that of the much smaller nucleus of deuterium.

The data were plotted as a function of Bjorken-x, which in deep-inelastic scattering is interpreted as the fraction of the nucleon's momentum carried by the struck quark. The binding energies of nucleons in the nucleus are several orders of magnitude smaller than the momentum transfers of deep-inelastic scattering, so, naively, such a ratio should be unity except for small corrections for the Fermi motion of nucleons in the nucleus. What the EMC experiment discovered was an unexpected downwards slope to the ratio (figure 1) – as revealed in *CERN Courier* in November 1982 and then published in a refereed journal the following March (Aubert *et al.* 1983).

This surprising result was confirmed by many groups, culminating with the high-precision electron- and muon-scattering data from SLAC (Gomez *et al.* 1994), Fermilab (Adams *et al.* 1995) and the New Muon collaboration (NMC) at CERN (Amaudruz *et al.* 1995 and Arneodo *et al.* 1996). Figure 2 shows representative data. The conclusions from the combined experimental evidence were that: the effect had a universal shape; was independent of the squared four-momentum transfer, $Q^2$; increased with nuclear mass number A; and scaled with the average nuclear density.

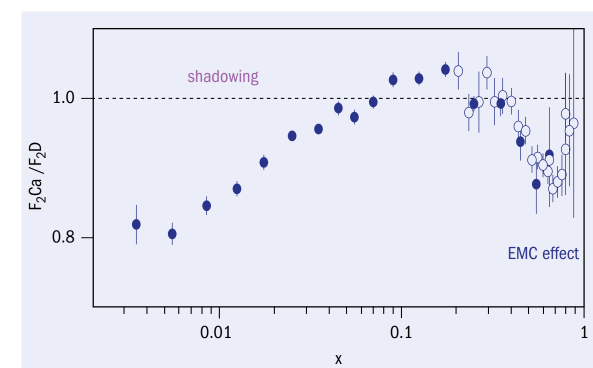



*Fig. 2. The ratio of the deep-inelastic cross-sections of calcium (Ca) to that of deuterium (D) from NMC (solid circles) and SLAC (open circles). The downward slope from $0.3 < x < 0.7$ and subsequent rise from $x > 0.7$ is a universal characteristic of EMC data and has became known as the EMC effect. The reduction of the ratio at lower values of x, where valence quarks should no longer play a significant role, is known as the shadowing region.*

### A simple picture

The primary theoretical interpretation of the EMC effect – the region $x > 0.3$ – was simple: quarks in nuclei move throughout a larger confinement volume and, as the uncertainty principle implies, they carry less momentum than quarks in free nucleons. The reduction of the ratio at lower x, named the shadowing region, was attributed either to the hadronic structure of the photon or, equivalently, to the overlap in the longitudinal ▷

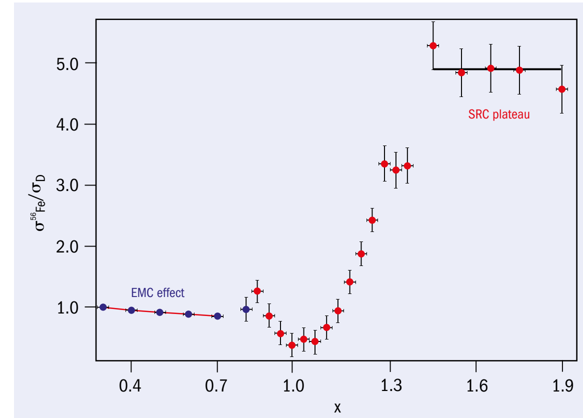



*Fig. 3. While figure 2 focuses on lower values of x, this focuses on the valence-quark region. In this region, the slope of the EMC effect in the region $0.3 < x < 0.7$ and the $x > 1$ plateaux from nucleon–nucleon short-range correlation (SRC) can be clearly seen. Both the EMC effect and the plateaux are more or less independent of $Q^2$, while the dip at $x = 1$ fills in as $Q^2$ increases.*

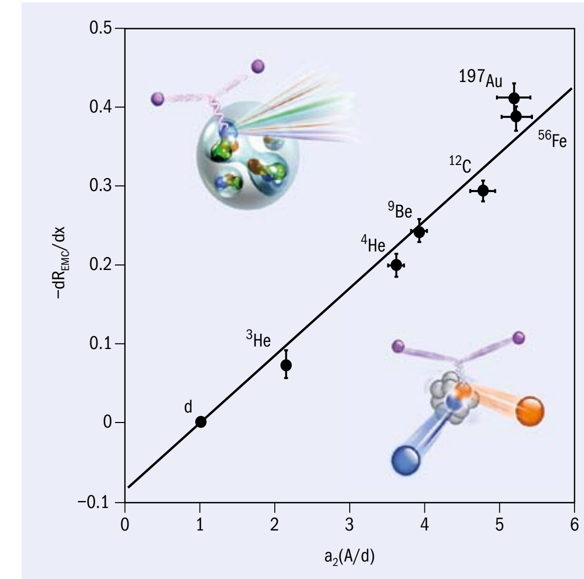



*Fig. 4. The slope of the EMC effect, dR/dx for $0.3 < x < 0.7$ with $R = F_2^A/F_2^D$, versus the magnitude of the observed $x > 1$ plateaux, denoted as $a_2$, for various nuclei. For data that were taken by completely different groups, the linearity is striking and has caused renewed interest in understanding the cause of both effects. The inset drawings illustrate the kinematic difference of deep-inelastic EMC-effect scattering and the scattering from a correlated pair in $x > 1$ kinematics.*

direction of small-x partons from different nuclei. These notions gave rise to a host of models: bound nucleons are larger than free ones; quarks in nuclei move in quark bags with 6, 9 and even up to 3A quarks, where A is the total number of nucleons. More conventional explanations, such as the influence of nuclear binding, enhancement of pion-cloud effects and a nuclear pionic field, were successful in reproducing some of the nuclear deep-inelastic scattering data.

It was even possible to combine different models to produce new ones; this led to a plethora of models that reproduced the data (Geesaman *et al.* 1995), causing one of the authors of this article to write that "EMC means Everyone's Model is Cool". It is interesting to note that none of the earliest models were that concerned with the role of two-nucleon correlations, except in relation to six-quark bags.

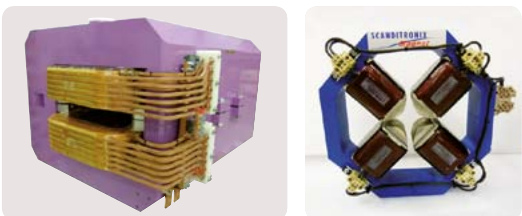
The initial excitement was tempered as deep-inelastic scattering became better understood and the data became more precise. Some of the more extreme models were ruled out by their failure to match well known nuclear phenomenology. Moreover, inconsistency with the baryon-momentum sum rules led to the downfall of many other models. Because some of them predicted an enhanced nuclear sea, the nuclear Drell-Yan process was suggested as a way to disentangle the various possible models. In this process, a quark from a proton projectile annihilates with a nuclear antiquark to form a virtual photon, which in turn becomes a leptonic pair (Bickerstaff *et al.* 1984). The experiment was done and none of the existing models provided an accurate description of both sets of data – a challenge that remains to this day (Alde *et al.* 1984).

### New data

A significant shift in the experimental understanding of the EMC effect occurred when new data on $^9$Be became available (Seely *et al.* 2009). These data changed the experimental conclusion that the EMC effect follows the average nuclear density and instead suggested that the effect follows local nuclear density. In other words, even in deep-inelastic kinematics, $^9$Be seemed to act like two alpha particles with a single nearly free neutron, rather than like a collection of nucleons whose properties were all modified.

This led experimentalists to ask if the $x > 1$ scaling plateaux (*CERN Courier* November 2005 p37) that have been attributed to short-range nucleon–nucleon correlations – a phenomenon that is also associated with high local densities (*CERN Courier* January/February 2009 p22) – could be related to the EMC effect. Figure 3 shows the kinematic range of the EMC effect together with the $x > 1$ short-range correlation (SRC) region. While the dip at $x = 1$ has been shown to vary rapidly with $Q^2$, the EMC effect and the magnitude of the $x > 1$ plateaux are basically constant within the $Q^2$ range of the experimental data. Plotting the slope of the EMC effect, $0.3 < x < 0.7$, against the magnitude of scaling $x > 1$ plateaux for all of the available data, as shown in figure 4, revealed a striking correlation (Weinstein *et al.* 2011). This phenomenological relationship has led to renewed interest in understanding how strongly correlated nucleons in the nucleus may be affecting the deep-inelastic results. ▷

**A significant shift in experimental understanding occurred when new data on $^9$Be became available**








## Anniversary

In February 2013, on nearly the 30th anniversary of the EMC publication, experimentalists and theorists came together at a special workshop at the University of Washington Institute of Nuclear Theory to review understanding of the EMC effect, discuss recent advances and plan new experimental and theoretical efforts. In particular, an entire series of EMC and SRC experiments are planned for the new 12 GeV electron beam at Jefferson Lab and analysis is underway of new Drell-Yan experimental data from Fermilab.

### A new life

Although the EMC effect is now 30 years old, the recent experimental results have given new life to this old puzzle; no longer is Every Model Cool. Understanding the EMC effect implies understanding how partons behave in the nuclear medium. It thus has far-reaching consequences for not only the extraction of neutron information from nuclear targets but also for understanding effects such as the NuTeV anomaly (*CERN Courier* September 2009 p9) or the excesses in the neutrino cross-sections observed by the MiniBooNe experiment (*CERN Courier* May 2007 p8).

### Further reading

For more about the workshop at the University of Washington Institute of Nuclear Theory, see www.int.washington.edu/PROGRAMS/13-52w/.

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### Résumé

*L'effet EMC, encore une énigme 30 ans après*

*Il y a trente ans, les membres de la collaboration EMC (Collaboration européenne du muon) au CERN découvraient un effet inattendu en rapportant leurs mesures de la diffusion profondément inélastique du muon au nombre de nucléons : les fonctions de structure étaient différentes s'agissant du fer et s'agissant du deutérium, qui est un noyau beaucoup plus léger. En représentant le rapport fer/deutérium en fonction de la fraction de l'impulsion du nucléon portée par le quark frappé, les expérimentateurs ont découvert une pente descendante inattendue. Ce résultat surprenant a été confirmé par de nombreux groupes, mais il reste une énigme. Des données récentes sur le 9Be ont relancé l'intérêt pour cette question, en montrant que des corrélations nucléon-nucléon à courte distance pouvaient être liées à l'effet EMC.*

**Douglas Higinbotham**, Jefferson Lab, **Gerald A Miller**, University of Washington, **Or Hen**, Tel Aviv University, and **Klaus Rith**, University of Erlangen-Nürnberg.








# Faces & Places

**Awards**

## Engineering prize honours internet and Web pioneers

Five engineers whose work, beginning in the 1970s, led to the internet and the World Wide Web have together won the inaugural Queen Elizabeth Prize for Engineering. Robert Kahn, Vinton Cerf, Louis Pouzin, Tim Berners-Lee and Marc Andreessen were announced on 18 March as the winners at the Royal Academy of Engineering in London.

Kahn, Cerf and Pouzin receive the award for their contributions to the protocols that make up the fundamental architecture of the internet. French computer scientist Pouzin invented the datagram and designed an early packet communications network known as CYCLADES in the early 1970s. His work was broadly used by Americans Kahn and Cerf in the development of TCP/IP. Berners-Lee created the World Wide Web at CERN in 1989 and American Marc Andreessen wrote the Mosaic browser that is credited with popularizing the Web.

By sharing their work freely and without restriction these pioneers allowed the internet and the Web to be adopted rapidly around the world and to grow organically thanks to open and universal standards. Additionally, they have served as technical and political stewards of the internet and the web over the past 30 years as it has grown from its experimental phase to hosting 50 billion pages of information today. Today a third of the world's population uses the internet and it is estimated to carry around 330 petabytes of data a year – enough to transfer every character ever written in every book ever published 20 times over.

The Queen Elizabeth Prize for Engineering is a £1 million global engineering prize designed to reward and celebrate the individuals responsible for a ground-breaking innovation in engineering that have benefited humanity. It is administered by the Royal Academy of Engineering.

The winners are due to come to London in June for the formal presentation of the prize at Buckingham Palace by Queen Elizabeth II.

*Tim Berners-Lee is reunited with the historic NeXT computer at CERN during celebrations for the 20th anniversary of the web in 2009 (*CERN Courier *May 2009 p24). He used this computer to develop and run the first Web server, multimedia browser and Web editor.*

*Recipients of the Fundamental Physics Prize Foundation's special prize in fundamental physics, announced in December (*CERN Courier *January/February 2013 p36), accepted their awards at a ceremony in Geneva on 20 March. The prize was shared by leaders of the LHC project and the CMS and ATLAS experiments from the time that the LHC was approved by the CERN Council in 1994. Here Guido Tonelli shares the stage with (left to right): Lyn Evans, Michel Della Negra, Tejinder Virdee, Peter Jenni, Joe Incandela and Fabiola Gianotti. Stephen Hawking also received a special prize, while quantum-field theorist Alexander Polyakov received the 2013 Fundamental Physics Prize for his work in field theory and string theory. The event was hosted by the actor Morgan Freeman, who took the opportunity to visit CERN and the LHC tunnel (right).*

SYMPOSIUM

# Imperial College celebrates Kibble's 80th birthday

Tom Kibble, one of the founding fathers of the Standard Model, turned 80 last December. To celebrate this milestone and Kibble's extraordinary contributions to theoretical physics, a one-day symposium was held on 13 March at Imperial College, London.

Kibble has made seminal contributions to the understanding of the mass-generating mechanism for elementary particles via symmetry breaking. Indeed, his profound papers of 1964 and 1967 provided key foundations for the Standard Model and inspired the search for the Higgs boson. He has also made significant contributions to the study of the dynamics of symmetry-breaking near phase transitions with diverse applications including to structure formation in the universe and vortices in helium-3.

The symposium profiled these and other aspects of Kibble's long scientific career. The two themes that resonated throughout the day were Kibble's extraordinary scientific achievements coupled with his humility.

The tenor of the meeting was set in the morning by Neil Turok, director of the Perimeter Institute for Theoretical Physics, who described Kibble as "our guru and example". He discussed Kibble's pioneering work on how topological defects might have formed in the early universe during symmetry-breaking phase transitions as the universe expanded and cooled. Wojciech Zurek of Los Alamos National Laboratory continued with this theme, surveying analogous processes within the context of condensed matter systems and explaining the famous Kibble-Zurek scaling phenomenon. Turok noted that while defects have been found everywhere in the lab, they are still to be seen in the universe, although many physicists remain hopeful.

*Tom Kibble, centre, with from left to right, Jim Virdee, John Hassard, Tariq Ali, Peter Dornan, John Pendry and Jordan Nash. (Images: Meilin Sancho, Imperial College.)*


*Weinberg gave the keynote presentation.*

The afternoon's events were concluded by Jim Virdee of Imperial College and the CMS experiment, who summarized the epic quest of finding the Higgs boson at the LHC. His talk surveyed the history of the LHC experiments and brought a rapt audience up to date with the latest data from CERN, all of which support the case that the new boson discovered last year is, indeed, a Higgs boson. At the end of the talk, there was a standing ovation for Kibble that lasted several minutes.

In the evening, Nobel laureate Steven Weinberg gave a stunning keynote presentation to a capacity audience of 700. With no visual props, he talked eruditely on symmetry breaking and its role in elementary particle physics. He emphasized the role played by the three 1964 papers by Robert Brout, François Englert, Peter Higgs, Gerald Guralnik, Carl Hagen and Kibble himself. He also emphasized the significant impact of Kibble's sole-authored 1967 paper that, among other things, explains the mechanism whereby the W and Z boson get mass while the photon remains massless.

At the banquet, the UK Minister of Science, David Willetts, praised Kibble's contributions to fundamental knowledge and the important ongoing role of Imperial College and the UK more generally. Ed Copeland of the University of Nottingham and Kibble's most prolific collaborator, profiled Kibble's scientific leadership, vision and generosity. Robert Kibble recollected that while his father was doing his amazing work, family life continued as normal – although holiday destinations did strangely seem to coincide with venues for physics conferences. Frank Close of Oxford University concluded the banquet speeches by summarizing the significance of Kibble's contributions to the Standard Model, again highlighting how his 1967 paper inspired Abdus Salam and Weinberg to realize that symmetry breaking could be applied to a marriage of the weak and electromagnetic interactions.

*Jerome Gauntlett, Imperial College.*

NEW PRODUCTS

**Kepco Inc** has announced new 1500 W and 3000 W models in its series of KLN automatic crossover, low-profile, high-performance, low-cost programmable power supplies. The KLN series offers stable DC power in a 1 U high, half-rack package for 750 W. They are now adding a 1 U high, full-rack package at 1500 W and a 2 U high, full-rack package at 3000 W. Output voltages range from 0–6 V to 0–600 V with output currents from 0–400 A to 0–1.25 A. For details, contact Saul Kupferberg, tel +1 718 461 7000, e-mail saulk@kepcopower.com or visit www.kepcopower.com/kln.htm.

**Maxon Motor** has introduced a modular multi-axis motherboard that can be applied with a few simple steps to suit drive systems with up to 11 axes. The EPOS motor-controller family comprises efficient, dynamic positioning controllers to operate brushed and brushless DC motors. The EPOS2 Module 36/2 is designed as a plug-in module for OEM system integration. For details, contact Eva Maria Amstutz, tel +41 41 666 1500, e-mail evamaria.amstutz@maxonmotor.com or visit www.maxonmotor.com.

**PI (Physik Instrumente) LP** has introduced the C-884, 4-axis digital servo controller, designed to control motorized linear translation stages and rotary positioners with high accuracy and repeatability. The high-speed encoder interface allows the use of direct-metrology linear and angular scales with resolutions below the nanometre and microrad regions. The controller has a dual-core architecture for fast servo handling and command interpretation. Communication is through industry standard TCP/IP, USB and RS-232 interfaces. For details, contact tel +1 508 832 3456, e-mail info@pi-usa.us or see www.pi-usa.us.

**Southern Scientific** has announced the DoseRAE 2, a compact, direct-reading, electronic personal radiation detector with alarm, which accurately accumulates real-time dose-data to allow immediate reaction in case of radiation occurrences. The device uses a compensated PIN diode and a caesium-iodide scintillation crystal to detect X and γ-radiation and provide high dose-rate range coverage, accurate dose measurements and fast response to low-level radiation. For more information, tel +44 1273 497600, or e-mail info@southernscientific.co.uk.



INAUGURATION

# Ceremony marks completion of ALMA telescope

In the vast Atacama Desert of the Chilean Andes, an official ceremony marked the inauguration of the Atacama Large Millimeter/submillimeter Array (ALMA) (*CERN Courier* October 2007 p23). More than 500 people attended the 13 March event, which signalled the completion of all major systems of the giant telescope and the formal transition from a construction project into an observatory.

A select group, including guest of honour Sebastián Piñera, the President of Chile, had the opportunity to visit the telescope, located 5000 m above sea level. The assembly of ALMA's antennas was recently completed, with the last batch of seven out of the final total of 66 antennas currently being tested before entering into service. The telescope has already provided unprecedented views of the cosmos using only a portion of its full array (*CERN Courier* November 2011 p13).

The ALMA array consists of 54 antennas with 12-m dishes and 12 smaller 7-m dishes, which work together as a single telescope. The signals from the individual antennas are brought together and processed by the "ALMA correlator" supercomputer. The 66 antennas can be arranged in different configurations, where the maximum distance between each one can vary from 150 m to 16 km.

ALMA is a partnership between scientific organizations and funding bodies in Europe, North America and East Asia, in co-operation with the Republic of Chile.

*Guests at the inauguration included the president of Chile, Sebastián Piñera, seen here (second from left) on an ALMA transporter with representatives from the European Southern Observatory, the US National Science Foundation, ALMA and Japan's Ministry of Education, Culture, Sports, Science and Technology. (Image credit: ESO/NAOJ/NRAO.)*

OBITUARIES

# Hugh Hereward 1920–2013

Hugh Hereward, one of the founding fathers of CERN, died on 20 February. As one of the leading accelerator physicists, he made essential contributions to the Proton Synchrotron (PS) and the Intersecting Storage Rings (ISR).

Hugh was born in 1920 in London to the family of an ocean-going captain of merchant vessels. He attended King Edward's High School in Birmingham, where a physics teacher who believed in his abilities encouraged him to specialize in the subject. With a scholarship to St John's College, Cambridge, where John Cockcroft was at the time, he took a shortened degree course and chose in 1942 to continue research rather than join the army. He was one of several physicists who, during the Second World War, contributed to the development of atomic energy in Hans von Halban's group at Cambridge, before moving to Montreal in 1943.

*Hugh Hereward, left, at CERN in 1961.*

After joining CERN in 1953, Hugh led the group that built the first 50 MeV linear accelerator used to inject protons into the PS, but he soon went on to study more general problems of accelerator theory. He became the great intellect whose chosen role was to study and analyse whatever knotty problems in accelerator theory were preventing a full understanding of the PS – and afterwards the ISR – to exploit the potential of each machine to the fullest.

He made essential contributions to the theory of linear accelerators, proposed and analysed in detail the slow resonant extraction of the PS beam and produced a number of now classic reports and lectures on matching and mismatching beams, beam instabilities and Landau damping, as well as on stochastic cooling. He also was one of the proponents of the ISR. Some of his memos were circulated in handwritten form but were so clear that his colleagues, when asked about these subjects 40 years later, will still search their filing cabinets for "something that Hereward wrote on this".

On first meeting, Hugh seemed a rather reserved and eccentric person. His well worn flannel trousers were supported by a broad leather belt whose tarnished buckle was fashioned into the insignia of the Boy Scouts, complete with the motto "Be prepared". We dared not ask if this was a reminder to himself or an exhortation to others. Colleagues would often consult him – the experience was reminiscent of a trip to Delphi. The question would be posed and a silence would follow, often long enough to induce unease in the questioner, who might be tempted to rephrase the question. This was unwise, for the clock would be restarted and another long pause would ensue – Hugh would seem disturbed that his thought process had been interrupted. Usually, the verdict would be delivered with gravity and precision but, failing that, the question would rebound in quite a different formulation, requiring further research on the part of the questioner.

Hugh's heyday was when he led the Machine Studies Team that developed the performance of the PS in the 1960s. He became leader by common acclaim and went on to fill the same role at the ISR. When by the mid-1970s, both the PS and the ISR had reached performance levels far beyond what anyone would have dared to forecast, he chose to retire from CERN, to live quietly in a village in the UK, while occasionally accepting consulting engagements for other laboratories in the US, Canada and Europe. Despite the decades that have passed since he left CERN, Hugh has remained vivid in the memory of all who had contact with him and benefited from his precious advice during those early years.

● *His former colleagues and friends.*
Based on an account in *Engines of Discovery* (World Scientific 2007) by Andrew Sessler and Edmund Wilson.

# Theodoros Kalogeropoulos 1931–2012

Theodoros (Ted) Kalogeropoulos, a distinguished physicist in elementary particle physics, and professor emeritus of Syracuse University, passed away on 7 September in Athens, Greece. His burial took place in Mallota – "the navel (the centre) of the earth" – as he used to call his village.

Ted was born on 20 January 1931 in the small village of Mallota in the prefecture of Arcadia, Greece, where his father was the village priest. His primary education began in Mallota and continued with high school in Magalopolis and later in Athens. He qualified in the Physics Department of the National and Kapodistrian University of Athens and received his diploma with high honours in 1954.

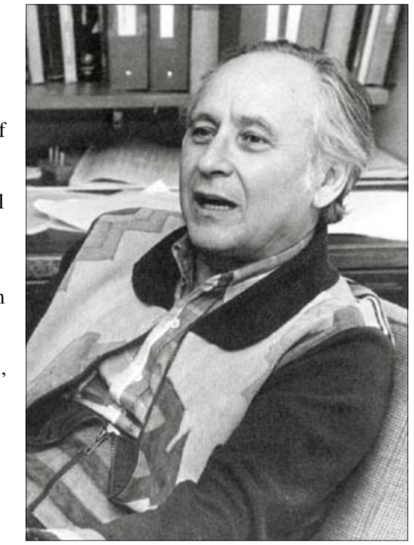
He then began graduate studies at the University of California, Berkeley, were he received his PhD in 1959 under Gerson Goldhaber. It was a golden period for Berkeley, where the antiproton had recently (1955) been discovered at the Bevatron at the Lawrence Radiation Laboratory. Ted's dissertation, "A study of the Antiproton Annihilation Process in Complex Nuclei", was an experiment with photographic emulsions. He collaborated with Owen Chamberlain, Emilio Segrè and Dick Dalitz and also participated in a bubble chamber experiment on pion-pion correlations in antiproton-annihilation events.

After receiving his PhD, Ted worked as a postdoc at Columbia University before joining the physics faculty at Syracuse University in 1962. There he continued his studies of antiproton interactions with protons and neutrons at rest and in flight at ▷

low energies, using bubble chambers, spark chambers, wire chambers, sodium-iodide crystals and novel time-of-flight techniques. From 1963 to 1984 he led an experimental group at Brookhaven National Laboratory. He was one of the world experts in the field of antiproton annihilations.

Ted played an important role when he joined the high-energy-physics experimental group of the "Demokritos" research centre in Greece during his sabbatical from Syracuse University and he continued this collaboration after his return to the US. From then on, he was concerned with organizing the development and progress of the Greek group. As a teacher he shared his enthusiasm, inspiring his students, including several Greek physicists who received their PhDs under his supervision, all of whom later became professors in Greek universities.

After a long involvement with the pure physics of antiprotons, Ted made use of their properties in medicine, diagnostic imaging and for therapeutic purposes. He published interesting basic papers on this subject, which has recently been revived by people working on the idea of using antiprotons for cancer therapy. After his retirement in 1998, Ted became professor emeritus at Syracuse and moved to Athens were he continued to work on research in medicine.


*Kalogeropoulos. (Image credit: Syracuse.)*

As a graduate student Ted married Nafsika, who died in Athens in 2009. She was always a great help to him, especially in the early years in the US. During the Syracuse period their house was an oasis for the Greek graduate students. To the students, the couple and their daughter Julie were like their own people at home.

We all recall Ted's generosity, his enthusiasm for research and his deep love for physics. Each time he was around his laugh could be heard from tens of metres away. His students, friends and colleagues will always remember him as a great personality.

● *Manolis Dris and Theodora Papadopoulou, National Technical University of Athens.*

# Paul Kienle 1931–2013

Paul Kienle began studying physics at the Technische Hochschule München (TH München) in 1949. For his diploma thesis he developed position sensitive Geiger-Müller counters, which he used in work for his doctoral thesis (1957) to measure radiation fields. Subsequently he spent more than a year at Brookhaven National Laboratory, where he was trained in health physics and radiation safety. Back at TH München he built up a radiation safety group at the new Research Reactor (FRM) in Garching and in parallel he started work on the application of the Mössbauer-effect, which led to his habilitation degree in 1962.

Shortly afterwards Paul became professor of radiation and nuclear physics at the Technische Hochschule Darmstadt, but in 1965 he returned to TH München (which was to be renamed the Technische Universität (TU) München) to become professor of experimental physics, joining his former teacher Heinz Maier-Leibnitz and his fellow student and friend Rudolf Mössbauer. In the following years, he and Ulrich Mayer-Berkhout from the Ludwig-Maximilians-Universität München were responsible for the construction of the Tandem Accelerator Laboratory of both Munich universities, which started operation in Garching in 1970.

In 1984 Paul became director of GSI in Darmstadt and led the design and construction of the Heavy Ion Synchrotron and the Experimental Storage Ring (ESR), which started operation in 1990. Two years later he returned again to TU München, but continued research in medium-energy heavy-ion physics at GSI. There he and his colleagues at the ESR discovered a new decay mode, bound β-decay, opening a new field in nuclear astrophysics and in studies of weak decays. In 1996, together with his long-time collaborators from Japan, he was involved in the discovery of deeply bound pionic nuclear states at GSI, which led to some of the first evidence for the partial restoration of spontaneous chiral symmetry-breaking of QCD in a nuclear medium.


*Paul Kienle. (Image credit: SMI.)*

Paul's vision to create new tools for the future is beautifully illustrated with his proposal in 1998 for the construction of the High Energy Storage Ring, as a new approach for physics with antiproton annihilation, which should soon become available at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt.

As professor emeritus at TU München from 1999, he continued his research and in 2002 became director of the Stefan Meyer Institute for Subatomic Physics in Vienna, focusing on experimental studies at GSI (the FOPI experiment), FAIR (PANDA) and the INFN Frascati National Laboratories (SIDDHARTA).

It was a great honour and pleasure to work with Paul and we would like to express our gratitude for, and appreciation of, his tremendous impact on modern nuclear science. We admired his enthusiasm in creating new methods and in triggering work on new technologies to solve open problems in physics. His passion for physics and his motto, *niemals aufgeben*, (never give up), will provide guidance and an obligation for us all.

● *His colleagues and friends from TU München, GSI, LNF-INFN and the SMI.*

# Wiktor Peryt 1944–2013

Wiktor Peryt, one of the pioneers who introduced and developed heavy-ion physics at Warsaw University of Technology (WUT), passed away on 15 January.

Peryt graduated from Warsaw University in 1968, where he specialized in nuclear physics. For his PhD, at JINR, Dubna, he made a quantitative comparison of results from bubble chambers with the theoretical predictions of the nuclear cascade model developed in Dubna, revealing new features in the reactions studied. As a by-product he developed useful computer methods for data analysis.

*Wiktor with the old electronics of the NA49 experiment. (Image credit: Jan Pluta.)*

At WUT, Peryt introduced computer methods into practical work in the student laboratories, allowing real physics data analysis. This led him later to organize the first national conference on Microcomputers in Physics Teaching, held at WUT in 1987. He also pioneered the introduction of CAMAC and VME systems into the teaching programme and organized "CAMAC", an academic circle where students learned how to use modular electronics and data-handling systems interfaced to computers.

Thanks to Peryt's contacts, the group at WUT joined the STAR experiment at Brookhaven, participating in R&D for the silicon vertex tracker. He also introduced the group to the NA49 and NA61/SHINE experiments at CERN. Under his leadership, WUT participated in all of the phases of NA61/SHINE, starting with the preparation of the project, then called "NA49 future". He led the work to replace the detector control system (DCS) almost completely and implement a new one based on EPICS (Experimental Physics and Industrial Control System), while still maintaining and operating the NA61 DCS. He attracted many talented students to NA61/SHINE, who have greatly contributed to software, detector and physics, and he organized numerous meetings of the NA49 and NA61/SHINE collaborations in WUT.

Peryt was also deputy leader of the WUT group in the ALICE collaboration at the LHC, contributing in particular to the construction and operation of the inner tracking system and the T0 trigger detector. However, Peryt's main responsibility concerned the design and implementation of the detector-construction database (DCDB), for which he mobilized a large number of students from several faculties at WUT. It was a big challenge and effort for him and for the young people to make project successful.

Recently, Peryt reactivated WUT's participation in experiments at JINR, Dubna. Using his experience from CERN, he initiated the group's contribution to the DCDB and DCS for the experimental Nuclotron-based Ion Collider fAcility (NICA) and Multi-Purpose Detector (MPD) at Dubna. In parallel, he was involved in a new education programme at WUT, leading a project supported by the European Union, in close collaboration with other nuclear institutions both in Poland and abroad.

As a collaborator, colleague and teacher, Peryt was rather restrained and far from making publicity of his activity and results. It was therefore sometimes surprising that he was able to attract many young people to work with him. Maybe, to understand this phenomenon, we should recall his poetic phrase on the role of electronics in physics experiments as "the grey roots of beautiful flowers" – not visible but leading to spectacular results. Now, after his passing, we see him also as "grey roots" – not promoting himself, but giving young people the possibilities of interesting work and a rapid rise in their career.

● *His former colleagues and friends.*

## Meetings

The **XXIX International Workshop on High Energy Physics** "New Results and Actual Problems in Particle & Astroparticle Physics and Cosmology" will take place on 26–28 June in Protvino, Moscow region. The purpose is to present a more complete and coherent picture of the understanding of the structure and dynamics of the microcosm, the megacosm and its evolution, and the relationship between these two extremes of modern physics. The workshop will cover both theory and experiment/observations. The aim will be to encourage much more critical discussion at the meeting than is usual, with workshop reports accompanied by discussion panels and talks. For details and deadlines (especially regarding Russian visas) see https://indico.cern.ch/conferenceDisplay.py?confId=211539.

**EPS-HEP 2013**, the 2013 Europhysics conference on High Energy Physics, organized by the High Energy and Particle Physics Division of the European Physical Society, will take place in Stockholm, on 18–24 July. Parallel and plenary sessions will be held at the Royal Institute of Technology and the Aula Magna at Stockholm University, respectively, with poster sessions throughout the conference. There will also be a joint ECFA-EPS session on Particle Physics after the European Strategy Update on the 20 July. For details and registration, see http://eps-hep2013.eu.

**HEP-MAD 13**, the 6th High-Energy Physics International Conference in Madagascar will be held on 4–10 September in Antananarivo. The conference, which is part specialized meeting and part introductory school, will discuss a range of theoretical and experimental physics from high-energy physics to astroparticle physics. These topics will be presented in the form of introductory reviews, short contributions and posters, complemented by national talks in other areas of physics. For details, see www.lpta.univ-montp2.fr/users/qcd/qcd2012/hepmad13/Welcome.html.

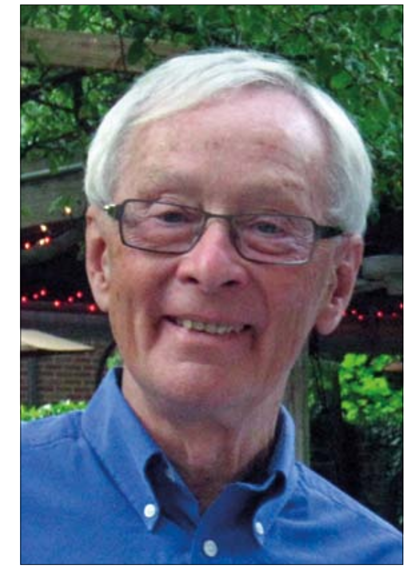




# William (Bill) J Willis 1932–2012

Today's vast and highly sophisticated particle detectors rely not only on many intertwining technological developments, but also on the ambition and vision of the particle physicists themselves. Over the past 50 years few have contributed as profoundly to the evolution of these detectors as Bill Willis, who died last November at the age of 80, after a short illness.

Bill was an undergraduate and PhD student at Yale and in the early part of his career he worked on the development of the bubble-chamber technique. He was an author on the famous 1964 paper announcing the discovery of the $\Omega^-$ and participated in several studies of hyperon decays at Brookhaven. He joined the Yale faculty in 1965 and, after initially seeking resources to pursue research with bubble chambers, he recognized the power and potential of what were at the time referred to as "counters", so he switched. He would later recall, with appreciation, the response of the Yale department-head to whom he announced this volte-face: "I worry much more about professors who never change their mind."



*Bill Willis. (Image credit: Columbia Univ.)*

Motivated by his research on weak decays, Bill began to think about ways to study decays into a lepton plus a neutrino in the environment of a hadron collider. He met Veljko Radeka, starting a life-long collaboration and friendship. One day in the early 1970s he drew on Radeka's blackboard a large circle, representing a sphere, with two tiny circles at the poles, explaining that the smaller circles were the holes for the colliding beams, and the large circle represented the volume in which the total energy of all particles (charged and neutral) should be measured and the leptons identified. Bill called his concept the "impactometer": it has become the standard approach for collider experiments.

The only hadron collider at the time being the Intersecting Storage Rings (ISR), Jack Steinberger was able to attract Bill to CERN, where he introduced him as "the cleverest physicist I know". There followed a decade of pioneering developments, notably liquid argon calorimetry, the detailed study of calorimeter resolution and transition radiation detectors. Deployment in experiments at the ISR led to the first observation of single-photon production at high $p_T$ and the co-discovery (with CERN's SppS collider) of high-$p_T$ jets, the latter through a first (approximate) realization of the "impactometer" in the form of the Axial Field Spectrometer. Throughout this period, Bill continued to collaborate closely with Radeka and with new colleagues at CERN, notably Chris Fabjan. He also developed fruitful links with several Russian colleagues, led by Boris Dolgoshein, who became collaborators and friends.

Starting in 1975, and extending for over 30 years, Bill spent some of his time at Brookhaven, initially to guide the development of experimentation for ISABELLE. But with ISABELLE's cancellation and the end of the ISR programme in the early 1980s, he seized the opportunity to promote a whole new field: the study of nuclear matter under extreme conditions of temperature and density as a means of searching for new forms of matter. He convinced the CERN management to adapt the Super Proton Synchrotron (SPS) to heavy-ion operation and to support an exploratory round of experiments. He was also instrumental in building the case for the Relativistic Heavy-Ion Collider (RHIC), which began operations at Brookhaven in 2000. The discoveries of a "new form of matter" at the SPS and of the strongly coupled quark–gluon plasma at RHIC are directly traceable to Bill's scientific vision. This programme continues today as a major research topic at the LHC.

Bill returned to the US in 1990, taking up a professorship at Columbia University, and became engaged in the Superconducting Super Collider (SSC). He was co-spokesperson of the GEM collaboration for the SSC and then, using his understanding and experience of both CERN and the US, he played a key co-ordinating role in bringing a large number of US scientists to the LHC programme, with major involvements in both ATLAS and CMS. Bill served as the US ATLAS Construction Project Manager until 2005 and was a member of the ATLAS Executive Board for four years. The performance of the ATLAS liquid argon calorimeter, not least in the discovery of the Higgs boson, should have given him a sense of real satisfaction – not that he would ever show it.

His range of activities and enthusiasm continued almost unabated. He was highly active in the International Linear Collider and most recently was involved in the MicroBooNE experiment, in which he combined his talent for developing ingenious approaches and his interest in novel detectors in the field of neutrino physics.

He served on numerous committees and panels, both in Europe and in the US, and, fittingly for someone who had close ties with many Russian physicists, as a Member of the Scientific Policy Committee of the Russian Ministry of Science. In 1993 he was elected to the American Academy of Science and in 2003 he received the W K H Panofsky Prize of the American Physical Society for "his leading role in the development and exploitation of innovative techniques now widely adopted in particle physics, including liquid argon calorimetry, electron identification by detection of transition radiation, and hyperon beams".

Bill was hugely respected for his incisive and original mind and for his many contributions to our field. But there was also the sheer delight of interacting with him at a personal level: none of us involved in the preparation of this article can remember him raising his voice, to anyone, ever. Two close collaborators concluded a review article on calorimetry in the early 1980s by writing "It is a pleasure to acknowledge the stimulation and interest arising from our association with W J Willis". In its quietly understated style it is a fitting tribute to a quietly understated man, who was one of the finest physicists of his generation. We are privileged to have known him and worked with him.

● *His friends and colleagues.*

# Recruitment

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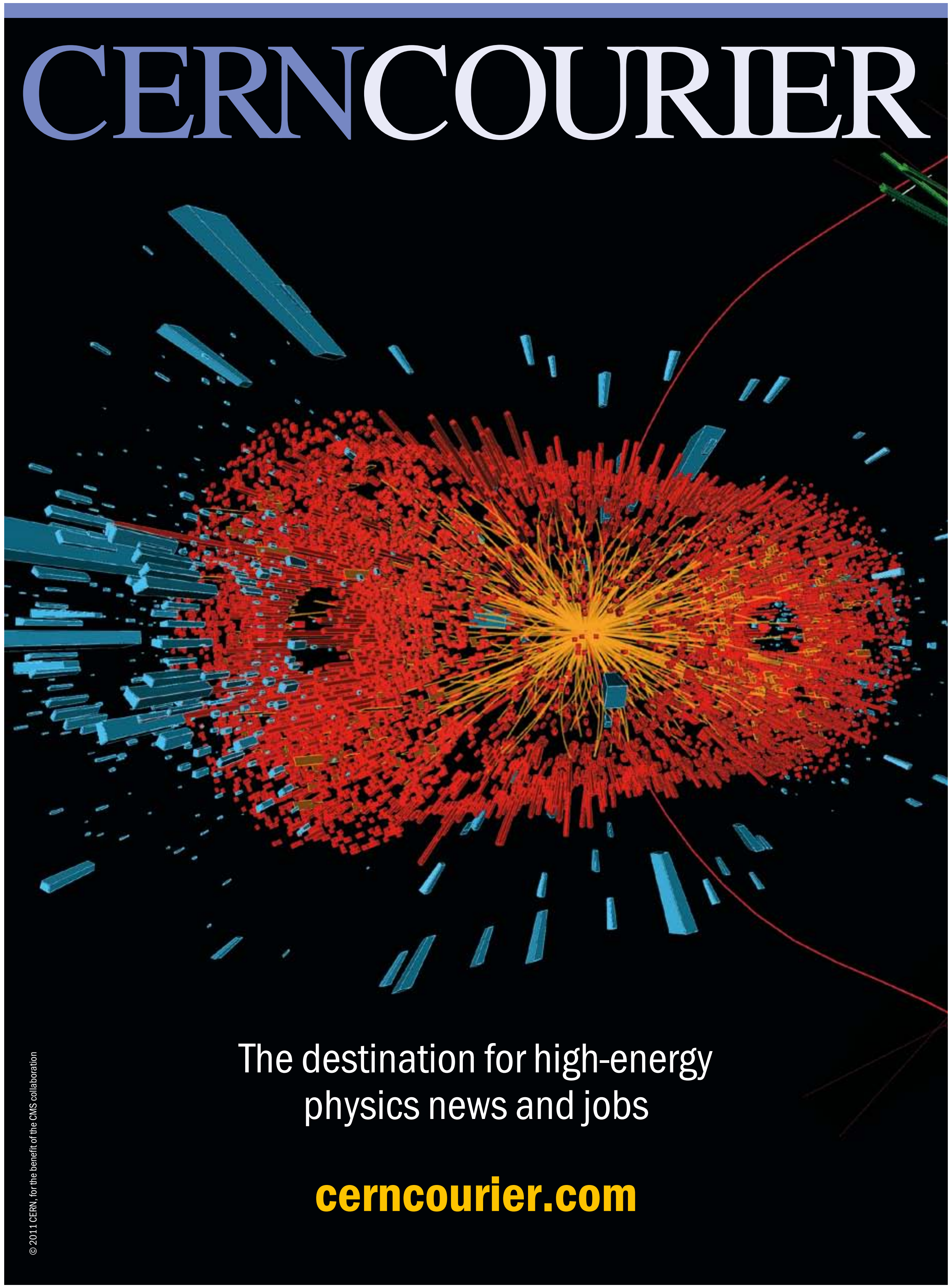
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# Bookshelf

## Imaging gaseous detectors and their applications

*By Eugenio Nappi and Vladimir Peskov*
**Wiley-VCH**
Hardback: €139
Paperback: €124.99


For those who belong to the Paleozoic era of R&D on gas detectors, this book evokes nostalgic memories of the hours spent in dark laboratories chasing sparks under black cloths, chasing leaks with screaming "pistols", taming coronas with red paint and yellow tape and, if you belonged to the crazy ones of Building 28 at CERN, sharing a glass of wine and the incredible maggoty Corsican cheese with Georges Charpak. Subtitle it "The sorcerer's Apprentice", and an innocent student might think they have entered the laboratory of Merlin: creating electrons from each fluttering photon, making magical mixtures of liquids, exotic vapours, funny thin films and all of the strange concoctions that inhabited the era of pioneering R&D and led step-by-step to today's devices.

The historical memory behind this book recalls all sorts of gaseous detectors that have been dreamt up by visionary scientists over the past 50 years: drift chambers, the ambitious time-projection chamber, resistive plate chambers, ring-imaging Cherenkov counters, parallel-plate avalanche counters, gas electron multipliers, Micromegas, exotic micro-pattern gaseous detectors (MPGDs) and more. All are included, both the ones that behaved and the ones that did not pay off – providing no excuse for anyone to re-make mistakes after reading the book. All of the basic processes that populate gas counters are reviewed and their functioning and limitations are explained in a simple and concise manner offering, to the attentive reader, key secrets and the solutions to obviate hidden traps. From the basic ionization processes to the trickiness of the streamer and breakdown mechanism, from the detection of a single photon to the problems of high rates – only lengthy, hands-on experience supported by a profound understanding of the physics of the detection processes could bring together the material that this book covers. Furthermore, it includes many notable explanations that are crystal clear yet also suitable for the theoretical part of a high-profile educational course.

Coming to more recent times, the use of microelectronics techniques in the manufacturing process of gas counters has paved the road to the new era of MPGDs. The authors follow this route, the detector designs and the most promising future directions and applications, critically but with great expectation, leaving the reader confident of many developments to come.

Each of us will find in this book some corner of our own memory, the significance of our own gaseous detector in recent and current experiments, together with a touch of the new in exploring the many possible applications of gas counters in medicine, biology or homeland security and – when closing the book – the compelling need to stay in the lab. *Chapeau!*

● *Ariella Cattai, CERN.*

## Books received

### Industrial Accelerators and Their Applications

*By Robert W Hamm and Marianne E Hamm (eds.)*
**World Scientific**
Hardback: £100
E-book: £127

This new book provides a comprehensive review of the many current industrial applications of particle accelerators, written by experts in each of these fields. Readers will gain a broad understanding of the principles of these applications, the extent to which they are employed and the accelerator technology utilized. It also serves as a thorough introduction to these fields for non-experts and laymen alike. Owing to the growing number of industrial applications, there is an increased interest among accelerator physicists and many other scientists worldwide in understanding how accelerators are used in various applications. Many industries are also doing more research on how they can improve their products or processes using particle beams.

### An Introduction to Non-Perturbative Foundations of Quantum Field Theory

*By Franco Strocchi*
**Oxford University Press**
Hardback: £55 $98.50

Quantum Field Theory (QFT) has proved to be the most useful strategy for the description of elementary-particle interactions and as such is regarded as a fundamental part of modern theoretical physics. In most presentations, the emphasis is on the effectiveness of the theory in producing experimentally testable predictions, which at present essentially means perturbative QFT. However, after more than 50 years of QFT, there is still no single non-trivial (even non-realistic) model of QFT in 3+1 dimensions, allowing a non-perturbative control. This book provides general physical principles and a mathematically sound approach to QFT. It covers the general structure of gauge theories, presents the charge superselection rules, gives a non-perturbative treatment of the Higgs mechanism and covers chiral symmetry breaking in QCD without instantons

### Novel Superfluids: Volume 1

*By Karl-Heinz Bennemann and John B Ketterson (eds.)*
**Oxford University Press**
Hardback: £125 $210

This volume reports on the latest developments in the field of superfluidity. The phenomenon has had a tremendous impact on the fundamental sciences as well as a host of technologies. In addition to metals and the helium liquids, the phenomenon has now been observed for photons in cavities, excitons in semiconductors, magnons in certain materials and cold gasses trapped in high vacuum. It very likely exists for neutrons in a neutron star and, possibly, in a conjectured quark state at their centre. Even the universe itself can be regarded as being in a kind of superfluid state. All of these topics are discussed by experts in the respective subfields.


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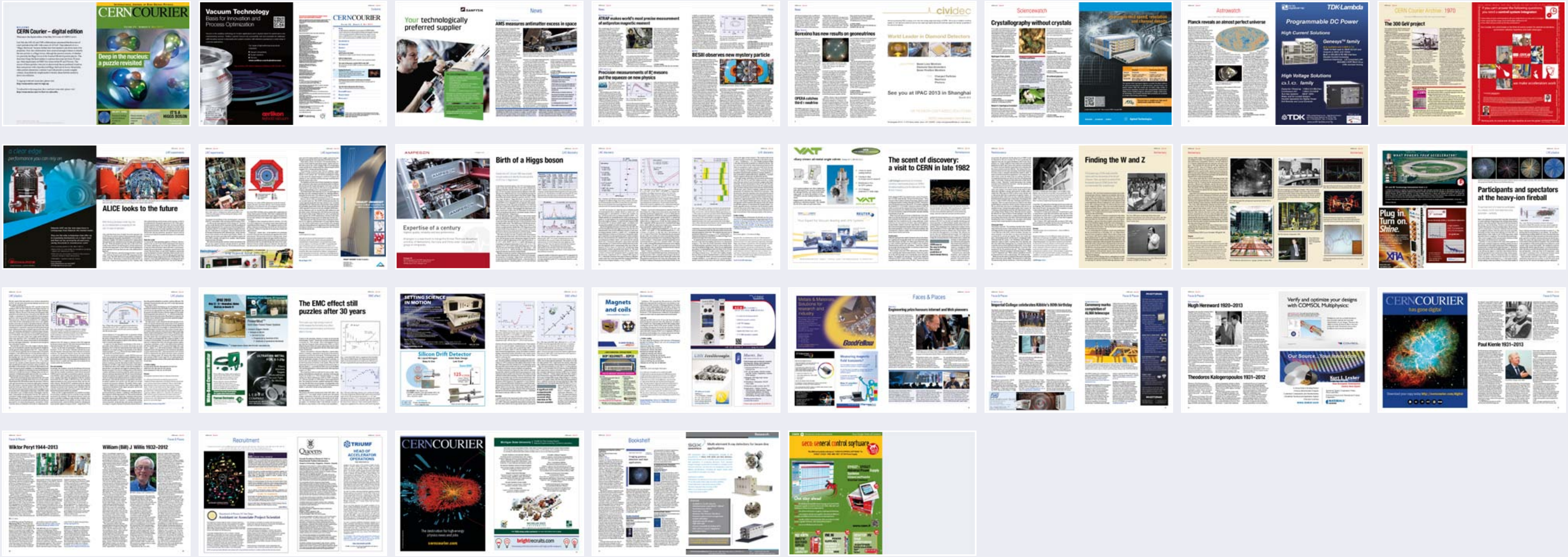


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