WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the March 2014 issue of *CERN Courier*.

In 1986, the start of the LAA project to study new experimental techniques for the next step in hadron-collider physics allowed CERN to join the era of microelectronics – essential for experiments at the LHC, where the conditions are challenging in many respects. The ALICE experiment is tackling puzzles surrounding quark–gluon plasma and under what conditions it is actually formed at the LHC. Elsewhere, antimatter provokes other questions, such as how does it behave with respect to gravity? Studies of this kind at the low-energy, high-precision frontier can cast light on physics that lies beyond the reach of the LHC.

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EDITOR: CHRISTINE SUTTON, CERN
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CERNCOURIER

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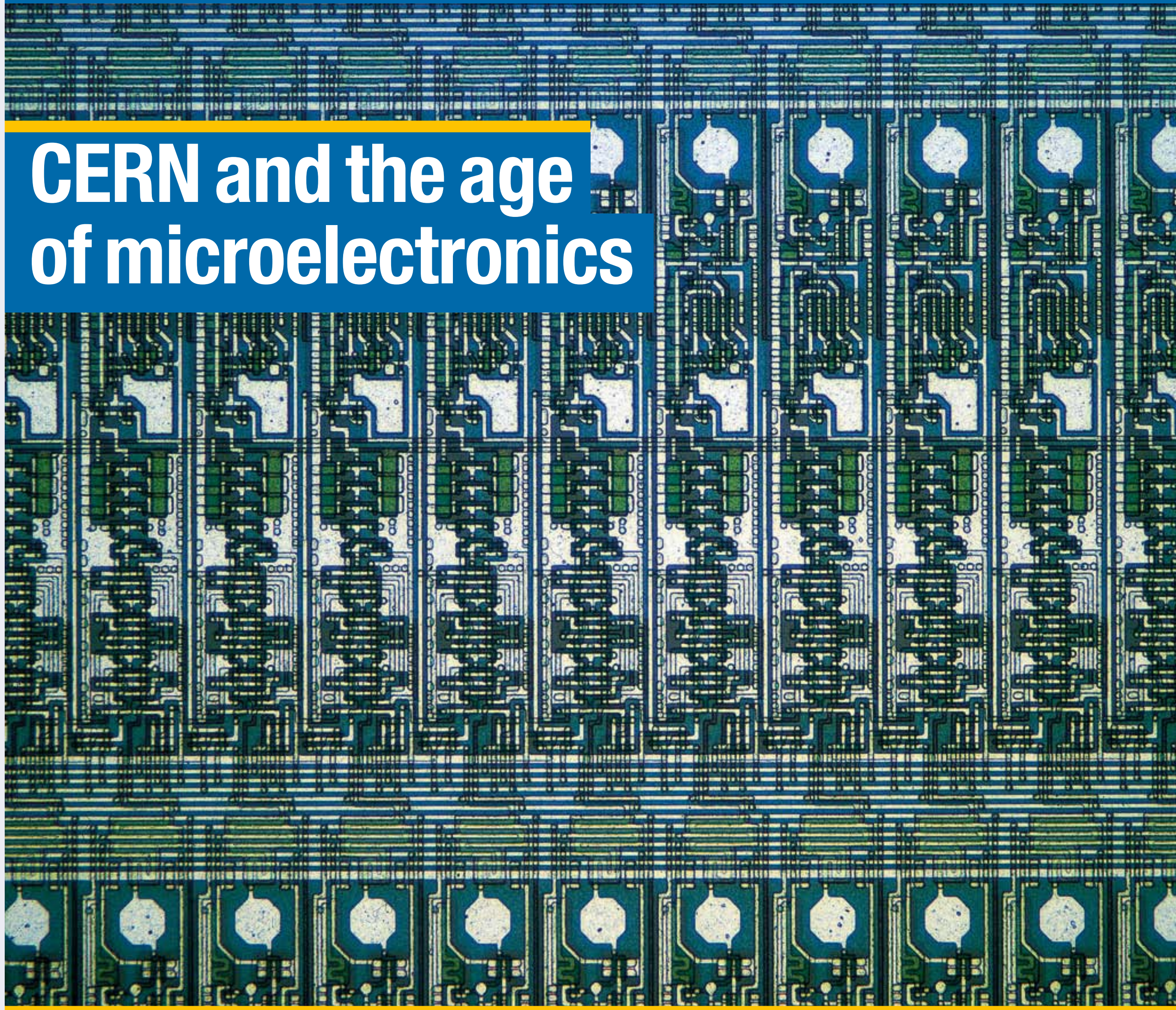
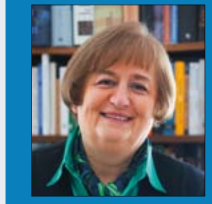


CERN and the age of microelectronics



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

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

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

Laboratory correspondents:
Argonne National Laboratory (US) Cosmas Zachos
Brookhaven National Laboratory (US) P Yamin
Cornell University (US) D G Cassel
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Publisher Susan Curtis
Production editor Lisa Gibson
Technical illustrator Alison Tovey
Group advertising manager Chris Thomas
Advertisement production Katie Graham
Marketing & Circulation Angela Gage

Head of B2B & Marketing Jo Allen
Art director Andrew Giaquinto

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

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Germany Antje Brandes, DESY, Notkestr. 85, 22607 Hamburg, Germany
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E-mail: loredana.rum@lnf.infn.it
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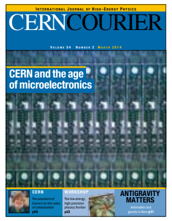


On the cover: One of the earliest pixel read-out chips developed at CERN. The launch of the LAA project in 1986 led directly to the build-up of expertise in microelectronics at CERN, laying crucial foundations for the subsequent success of the LHC experiments (p26).

News

CERN

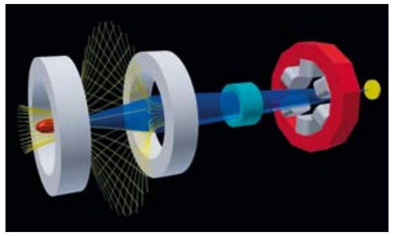
ASACUSA produces first beam of antihydrogen atoms for hyperfine study

A beam of antihydrogen atoms has for the first time been successfully produced by an experiment at CERN's Antiproton Decelerator (AD). The ASACUSA collaboration reports the unambiguous detection of antihydrogen atoms 2.7 m downstream from their production, where the perturbing influence of the magnetic fields used to produce the antiatoms is negligibly small. This result is a significant step towards precise hyperfine spectroscopy of antihydrogen atoms.

High-precision microwave spectroscopy of ground-state hyperfine transitions in antihydrogen atoms is a main focus of the Japanese-European ASACUSA collaboration. The research aims at investigating differences between matter and antimatter to test CPT symmetry (the combination of charge conjugation, C, parity, P, and time reversal, T) by comparing the spectra of antihydrogen with those of hydrogen, one of the most precisely investigated and best understood systems in modern physics.

One of the key challenges in studying antiatoms is to keep them away from ordinary matter. To do so, other collaborations take advantage of antihydrogen's magnetic properties and use strong, non-uniform magnetic fields to trap the antiatoms long enough to study them. However, the strong magnetic-field gradients degrade the spectroscopic properties of the antihydrogen. To allow for clean, high-resolution spectroscopy, the ASACUSA collaboration has developed an innovative set-up to transfer antihydrogen atoms to a region where they can be studied in flight, far from the strong magnetic field regions.

In ASACUSA, the antihydrogen atoms are formed by loading antiprotons and positrons into the so-called cusp trap, which combines the magnetic field of a pair of superconducting anti-Helmholtz coils (i.e., coils with antiparallel excitation currents) with the electrostatic potential of an assembly of multi-ring electrodes (*CERN Courier* March 2011 p17). The magnetic-field gradient allows the flow of spin-polarized antihydrogen atoms along the axis of the cusp trap. Downstream there is a spectrometer consisting of a microwave cavity to induce spin-flips in the antiatoms, a superconducting sextupole magnet to focus the neutral beam and an antihydrogen detector. (The microwave cavity was not installed in the 2012 experiment.)



A schematic drawing of the cusp-trap scheme. Left to right: the cusp trap to produce antihydrogen atoms, a microwave cavity (green) to induce hyperfine transitions, a sextupole magnet (red and grey) and an antihydrogen detector (gold). (Image credit: Stefan Meyer Institut.)

The detector, located 2.7 m from the antihydrogen-production region, consists of single-crystal bismuth germanium oxide (BGO) surrounded by five plates of plastic scintillator. Antihydrogen atoms annihilating in the crystal emit three charged pions on average, so the signal required consists of a coincidence between the crystal and at least two plastic scintillators. Simulations show that this requirement reduces the background, from antiprotons annihilating upstream and from cosmic rays, by three orders of magnitude.

The ASACUSA researchers investigate the principal quantum number, n, of the antihydrogen atoms that reach the detector, because their goal is to perform hyperfine spectroscopy on the ground state, $n = 1$. For these measurements, field-ionization electrodes were positioned in front of the BGO, so that only antihydrogen atoms with $n < 43$ or $n < 29$ reached the detector, depending on the average electric field. The analysis indicates that 80 antihydrogen atoms were unambiguously detected with $n < 43$, with a significant number having $n < 29$.

This analysis was based on data collected in 2012, before the accelerator complex at CERN entered its current long shutdown. Since then, the collaboration has also been preparing for the restart of the experiment at the AD in October this year. A new cusp magnet is under construction, which will provide a much stronger focusing force on the spin-polarized antihydrogen beam. A cylindrical high-resolution tracker and a new antihydrogen-beam detector are also under development. In addition, the positron accumulator will lead to an order of magnitude more positrons. The team eventually needs a beam of antihydrogen in its ground state ($n = 1$) so the updated experiment will employ an ionizer with higher fields to extract antihydrogen atoms that are in effect in the ground state.

Further reading

N Kuroda *et al.* 2014 *Nature Communications* **5** doi:10.1038/ncomms4089.

Sommaire en français

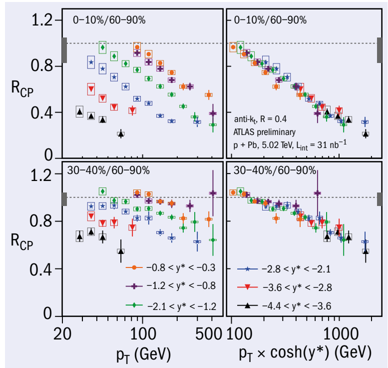
LHC PHYSICS

Jets give clues to the geometry of proton–nucleus collisions

Studies of the centrality-dependence of jet production in proton–lead collisions in ATLAS at the LHC are yielding surprising results.

In both proton–ion and ion–ion collisions, many interesting phenomena are influenced by the initial geometry of the collision system. In proton–nucleus collisions, protons that strike the centre of the nucleus (central collisions) see a thicker nuclear target than those that strike the edge (peripheral collisions) and are more likely to undergo a hard scattering. Traditionally, the geometry of the collisions or "centrality" is characterized by a measure of the event activity. For this measurement in ATLAS, the centrality is defined by the total transverse energy in the forward calorimeter in the direction of the lead beam. A model that describes the expected geometric enhancement of hard-scattering rates is used to relate this experimental measure to a factor T_A (Miller *et al.* 2007).

The quantity R_{CP} is defined as the ratio of the per-event jet yields in different centrality bins divided by the ratio of corresponding T_A factors, which account for the expected geometric enhancement. The left panels of the figure show R_{CP} values as a function of the jet transverse-momentum, p_T, for different ranges in jet rapidity, y*, in the centre-of-mass frame. Negative y* indicates the proton-going direction. The normalized jet ratio, R_{CP}, is suppressed at high p_T and large negative y* compared with the expectation from known nuclear effects, which would correspond to a value near unity in R_{CP}. The suppression of jets is strongest in the most central collisions (0–10%) at the highest p_T values. Additional studies, independent of the centrality definition, indicate that final-state energy-loss like that observed in ion–ion collisions (jet quenching) is unlikely to be the main source of the effect.



R_{CP} for R = 0.4 jets in $\sqrt{s_{NN}} = 5.02$ TeV proton–lead collisions. Each panel shows the R_{CP} value in jets in multiple rapidity bins at a fixed centrality interval. The top row shows R_{CP} for 0–10%/60–90% and the bottom row shows RCP for 30–40%/60–90%. In the left column, R_{CP} is plotted versus jet p_T. In the right column, R_{CP} is plotted against the quantity $p_T$cosh(y), where y* is the midpoint of the rapidity bin. Error bars on data points represent statistical uncertainties, boxes represent systematic uncertainties, and the shaded box on the $R_{CP} = 1$ dotted line indicates the systematic uncertainty for that centrality interval.*

These results suggest either a correlation between hard-jet production and soft-particle production that breaks the traditional geometric paradigm, or that in proton–lead collisions the energy in the forward calorimeter is not a good measure of the centrality of the collision in events with jets.

The right panel of the figure shows the jet R_{CP} as a function of $p_T$cosh(y*), which corresponds closely to the jet's energy. When recast in terms of this quantity, the R_{CP} values from different y* intervals all fall along the same line. Whether this is coincidence or related to the underlying dynamics is not yet known.

These observations are among the most striking preliminary ATLAS results from the 2013 proton–lead run of the LHC. Further measurements are needed to uncover the mechanism underlying the observed soft–hard correlations.

Further reading

ATLAS collaboration 2013 ATLAS-CONF-2013-105.

M L Miller *et al.* 2007 *Ann. Rev. Nucl. Part. Sci.* **57** 205.

CMS observes new single-top production mode

The top quark remains, nearly 20 years after its discovery by the experiments at Fermilab's Tevatron, the heaviest particle known. Its production and decays continue to be the subjects of extensive studies, both at the Tevatron and at the LHC. While top quarks are predominantly produced in pairs through the strong interaction, the production of single top quarks is also possible by virtue of the electroweak interaction, albeit with a much smaller production cross-section. This latter production mechanism provides a unique window into the dynamics of the top quark.

Three different production channels for single top quarks can be distinguished: the t-channel, the s-channel and the W-associated channel (figure 1). After many years of intensive searches, the Tevatron experiment collaborations first reported the observation of singly produced top quarks in 2009. These initial searches were optimized for the t- and s-channel production modes combined. Later, the t-channel mode was individually established by experiments at the Tevatron and the LHC, while evidence for s-channel production was reported only recently by the D0 collaboration at the Tevatron, in July 2013.

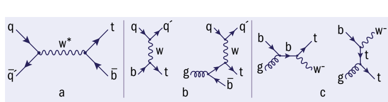


Fig. 1. Feynman diagrams for the electroweak production of single top quarks in the s-channel (a), in the t-channel (b), and for W-associated production (c).

Meanwhile, the third production mechanism, W-associated production, remained out of the Tevatron's reach because of its small cross-section and the lack of a sufficiently distinctive signature. At the LHC, however, the production rate for top quarks is much higher. This allowed ATLAS and CMS to report evidence of W-associated production already with the data collected at a centre-of-mass energy of 7 TeV in 2011, although these measurements did not reach the 5σ gold standard for the solid observation of a new signal. Now, thanks to the data collected in 2012 with the LHC operating at a centre-of-mass energy of 8 TeV, the CMS collaboration has been able to complete the experimental picture of the family of single top-quark production mechanisms.

The main background to W-associated production comes from pair-produced top quarks, where the decay of one of the top quarks appears W-like, because the b quark into which it decays fails the b-tagging requirements. No single defining feature separates the two processes sharply, so several kinematic properties have been combined into a single multivariate discriminant by a boosted decision tree – a machine-learning technique that is particularly suited to separating tiny signals from overwhelming backgrounds. Figure 2 shows the discriminant from the boosted decision tree.

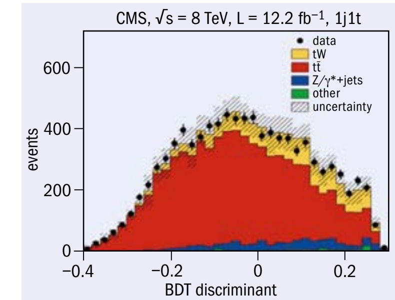


Fig. 2. The discriminant from the boosted decision tree in the final state with two light leptons (electron or muon) and one b-tagged jet.

The amount of signal in the selected sample is inferred by a fit to the discriminant distribution. To constrain tightly the amount of top-quark pair background with the data, two complementary samples with one additional jet, separated into cases with one or both jets b-tagged, are also included in the fit. The relative population of the samples with one or two b-tagged jets – both of which are almost pure in top-quark pair events – proves to be a powerful handle to reduce the uncertainty on the b-tagging efficiency, and therefore improve the precision of the analysis.

The excess of events with respect to the background-only hypothesis is quantified at a significance of 6.1σ (with 5.4±1.4σ expected from simulation), and the cross-section is found to be 23.4±5.4 pb, in agreement with the Standard Model prediction. Two cross-check analyses, less sensitive but relying on fewer modelling assumptions, confirm the result, therefore further supporting the first-time observation of this new single-top production mode.

This result opens the door to future searches for anomalous interactions of the top quark with the W boson, in a production mode that brings complementary information to studies that have so far been performed only with selections optimized for the more abundant top-pair and single top-quark t-channel events.

Further reading

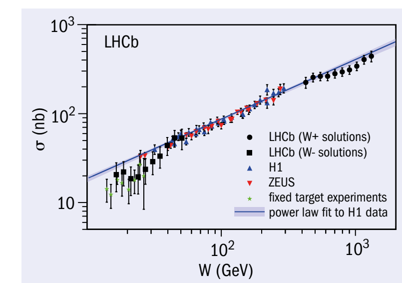
CMS collaboration 2014 *arXiv*:1401.2942 [hep-ex], submitted to *Phys. Rev. Lett.*

Charmonium produced in unusual topology sheds light on QCD

The LHCb collaboration has released updated measurements of central exclusive production of the J/ψ and ψ(2S) mesons (LHCb collaboration 2014).

Central exclusive production is a class of reactions in which one or two particles are produced from a beam collision, but the colliding hadrons emerge intact. At the LHC this leads to an unusual and distinctive topology of low-multiplicity events contained in a small rapidity interval with large rapidity gaps on either side. J/ψ and ψ(2S) mesons are produced when a photon emitted from one proton interacts with a pomeron (a colourless combination of gluons) from the other. Measurements of the process can be used to test QCD predictions – to improve our understanding of the distribution of quarks inside the proton – and are also sensitive to saturation effects.

LHCb's ability to trigger on low-momentum particles and the low number of proton–proton interactions per beam crossing provide an ideal environment to study these processes with particularly low multiplicity. Using data collected in 2011, around 56,000 central exclusive J/ψ and 1500 ψ(2S) mesons have been identified by reconstructing their decays to pairs of muons. While non-resonant backgrounds are very small, the challenge in the analysis is to estimate the larger background that arises when J/ψ and ψ(2S) mesons are produced and one or both of the colliding protons dissociate. As LHCb is instrumented in the forward region mainly, this effect often cannot be detected directly. Instead the collaboration has developed methods to estimate the background rate from the portion of events that are detected.



The J/ψ and ψ(2S) photoproduction cross-section measured by LHCb as a function of the photon–proton centre-of-mass energy (W).

The measured cross-sections are compared to theoretical predictions, as well as to photoproduction measurements from the HERA electron–proton collider and from fixed-target experiments. Although these environments are quite different from collisions at the LHC, the underlying process is the same. In the former a photon is emitted from an incoming electron beam, while the latter use photon beams directly.

The figure shows a model-dependent comparison of the LHCb results with those from the other types of experiment. It plots the photoproduction cross-section as a function of the photon–proton centre-of-mass energy (W). There is a two-fold ambiguity in converting LHCb's proton–proton differential cross-section to a photoproduction cross-section, corresponding to the photon being either an emitter or a target. This is resolved using recent results from the H1 experiment at HERA (H1 collaboration 2013). The data in the figure show broad consistency over two orders of magnitude, but are in marginal agreement with a single power-law distribution expected from leading-order QCD. Better agreement is provided either at next-to-leading order QCD (Jones *et al.* 2013) or by including saturation effects (Gay Ducati *et al.* 2013).

Further reading

M B Gay Ducati *et al.* 2013 *arXiv*:1305.4611 [hep.ph].

H1 collaboration 2013 *Eur. Phys. J.* **C73** 2466.

S P Jones *et al.* 2013 JHEP **1311** 085.

LHCb collaboration 2014 *arXiv*:1401.3288 [hep-ex].

GSI

Heavy-ion synchrotron prepares for FAIR

Elaborate alterations to the Schwerionensynchrotron (SIS) – the heavy-ion synchrotron at GSI – have finished after one year's work. The main new feature is an additional accelerator cavity, so that the accelerator now has a total of three cavities. The remodelling of the SIS accelerator was necessary for it to serve in future as an injector for the Facility for Antiproton and Ion Research (FAIR). The FAIR accelerator complex, which is currently under construction through an international effort, will be connected to the existing GSI facility.

The SIS after reconstruction with the new acceleration section installed. (Image credit: Gaby Otto/GSI.)

The SIS accelerator has a circumference of 216 m, with about 50 magnets – each weighing several tonnes – to keep the particles on the correct path. In the coming years, two further accelerator cavities will be added. With a total of five cavities, the SIS will have the performance that is required to accelerate all kinds of elements and inject them into the FAIR machines.

Since its commissioning in 1990, SIS has been the scene of many successes, including the discovery of hundreds of new isotopes – a field in which a GSI scientist holds the world record – and three new types of radioactive decay. Work on SIS in biophysics also led to the development of ion-beam therapy at GSI, where 450 patients were successfully treated. This method of cancer therapy is now routinely administered at the HIT facility in Heidelberg, using a dedicated accelerator built by GSI.

Fermilab

LBNE prototype cryostat exceeds goals

Scientists and engineers working on the design of the particle detector for the Long-Baseline Neutrino Experiment (LBNE) celebrated a major success in January. They showed that very large cryostats for liquid-argon-based neutrino detectors can be built using industry-standard technology normally employed for the storage of liquefied natural gas. The 35-tonne prototype system satisfies LBNE's stringent purity requirement on oxygen contamination in argon of less than 200 parts per trillion (ppt) – a level that the team could maintain stably.

The purity of liquid argon is crucial for the proposed LBNE time-projection chamber (TPC), which will feature wire planes that collect electrons from an approximately 3.5 m drift region. Oxygen and other electronegative impurities in the liquid can absorb ionization electrons created by charged particles emerging from neutrino interactions and prevent them from reaching the TPC's signal wires.

The test results were the outcome of the first phase of operating the LBNE prototype cryostat, which was built at Fermilab and features a membrane designed and supplied by the IHI Corporation of Japan. As part of the test, engineers cooled the system and filled the cryostat with liquid argon without prior evacuation. On 20 December, during a marathon 36 hour session, they cooled the membrane cryostat slowly and smoothly to 110 K, at which point they commenced the transfer of some 20,000 litres of liquid argon, maintained at about 89 K, from Fermilab's Liquid-Argon Purity Demonstrator to the 35 tonne cryostat. By the end of the session, the team was able to verify that the systems for purifying, recirculating and recondensing the argon were working properly.

Fermilab technician John Najdzion, standing on top of the LBNE 35-tonne prototype cryostat, works on the piping for the cryogenic systems. (Image credit: Fermilab Media Services.)

The LBNE team then topped off the tank with an additional 6000 litres of liquid argon and began to determine the argon's purity by measuring the lifetime of ionization electrons travelling through the liquid, accelerated by an electric field of 60 V/cm. The measured electron lifetimes were between 2.5 and 3 ms – corresponding to an oxygen contamination approaching 100 ppt and nearly two times better than LBNE's minimum requirement of 1.5 ms.

The Phase II testing programme, scheduled to begin at the end of 2014, will focus on the performance of active TPC detector elements submerged in liquid argon. Construction of the LBNE experiment, which will look for CP violation in neutrino oscillations by examining a neutrino beam travelling 1300 km from Fermilab to the Sanford Underground Research Facility, could begin in 2016. More than 450 scientists from 85 institutions collaborate on LBNE.

Jefferson Lab

New recipes for stopping neutrons

Neutrons are a common by-product of particle-accelerator operations. While these particles can be studied or gainfully used, at other times they are a nuisance, with the potential to damage sensitive electronics and cause data-acquisition systems to fail mid-experiment.

Preventing neutrons from causing damage was a chief goal in the design of a shield house for an apparatus being built for the 12 GeV Upgrade project being carried out at the US Department of Energy's Jefferson Lab. The $338 million upgrade will double the energy of the electron beam, adding an additional experimental hall while improving the existing halls along with other upgrades and additions (*CERN Courier* November 2012 p30).

The new apparatus, the Super High Momentum Spectrometer (SHMS), will enable measurements at high luminosity of particles with momentum approaching the beam energy, scattered at forward angles. It complements the existing High Momentum Spectrometer (HMS).

The physicists and engineers designing the SHMS shield house capitalized on data from more than 15 years of operations with the HMS and various large, open detector systems operated at Jefferson Lab. Using Monte Carlo calculations carried out with Geant4, material specifications were optimized for shielding the electronics from neutrons. However, current technologies did not meet the requirements. Existing systems were too bulky, expensive and difficult to manufacture. So a new system was designed, consisting of three parts: a hydrogen-rich and lightweight concrete layer to thermalize neutrons, a boron-rich concrete layer to absorb them and a thin lead layer to halt residual radiation.

The hydrogen-rich, lightweight concrete is the main structural component of the shield house. This material lacks most of the grit and rocks in ordinary concrete and instead contains shredded plastic and lightweight shale. It looks and pours like concrete and has the same strength, but it has two-thirds of the weight and has four times the neutron-thermalizing capability.

The boron-rich concrete is similarly produced using a patented new recipe, with boron powder replacing the typical aggregate. The boron-rich concrete has the same consistency and strength as ordinary concrete and concrete simply doped with boron, yet stops neutrons with less material. A protective layer that is 15 cm thick encloses concrete electronics rooms in the SHMS shield house, topped with thin lead plates to stop the 0.48 MeV γ rays produced in neutron–boron interactions. A third, panel-like product was designed to stop neutrons in space-constricted areas. It is about 2.5 cm thick and consists of boron embedded in an epoxy resin.

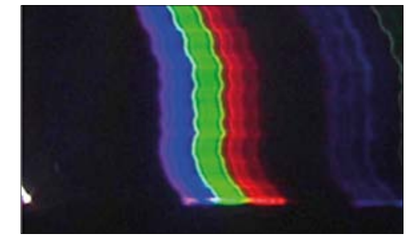
All of the new products are easily manufactured using existing techniques, and systems built with these patented and patent-pending technologies have applications in nuclear-waste storage, compact nuclear reactors and for shielding radiation sources in medical applications.

Sciencewatch

Compiled by John Swain, Northeastern University

Ball lightning reveals its secrets

Ball lightning has been an ongoing puzzle for centuries, largely because of a lack of good observations. Now, Jianyong Cen and colleagues at Northwest National University in Gansu, China, have had the good fortune to film ball lightning and measure its emission spectrum during an experiment intended to study normal cloud-to-ground lightning. In addition to having details on the size, colour and brightness as a function of time, they find significant emission lines from elements in soil, including silicon, iron and calcium. This supports various models where ball lightning is produced from a discharge hitting the ground and comprises not just atmospheric elements, but bits of soil as well.



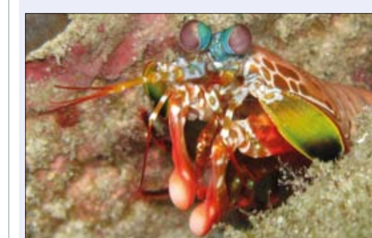
The spectrum of a cloud-to-ground lightning strike and of the ball lightning it generated. The ball lightning is the white dot at the far left.

Further reading
J Cen *et al.* 2014 *Phys. Rev. Lett.* **112** 035001.

Mantis shrimp vision

Most people are familiar with human colour vision being based on three receptors covering, roughly speaking, red, green and blue. The mantis shrimp, remarkably, has 12 different photoreceptor types, each covering a narrow range of wavelengths from deep UV to far red. This, of course, begs the question "why?" Hanne Thoen of the University of Queensland and colleagues have shown that the shrimp seems to encode image colours as a temporal sequence of receptor signals as its eyes scan across an object – analogous to "push-broom" spectral analysers used in remote sensing. This reduces the need for processing in the shrimps' brains and seems to represent a unique approach to image coding in animal vision.

Further reading
H H Thoen *et al.* 2014 *Science* **343** 411.



The mantis shrimp: its eyes have many colour receptors. (Image credit: SIlke Baron / CC BY 2.0.)

First-photon imaging

A novel form of camera developed by Ahmed Kirmani and colleagues at Massachusetts Institute of Technology can capture 3D structure and reflectivity information with very little light. A pulsed laser illuminates points on the object with short flashes until a single scattered photon is detected with a fast Geiger-mode avalanche photodiode detector. The number of times the laser has to fire for a photon to come back gives a measure of the reflectivity of each point being fired at. A computer system uses expected correlations in reflectivity and the position of nearby points on an object reduces noise from Poisson statistics and constructs an image. The technique requires 900 times less light than conventional imaging and could be useful for taking pictures of light-sensitive objects, or taking pictures in the dark without giving away the photographer's presence.

Further reading
A Kirmani *et al.* 2014 *Science* **343** 58.

Volcanic lightning

Lightning is often seen in volcanic eruptions – a phenomenon that has now been replicated in the laboratory. C Cimarelli of Ludwig Maximilian University in Munich and colleagues used rapid decompression of gas-particle mixtures to produce and study volcanic lightning under controlled conditions. The particles were actual volcanic ash from volcanoes including Popocatépetl in Mexico and Eyjafjallajökull in Iceland (which caused so much disruption to travel in April 2010). Rapid progress is now expected in improving the understanding of this natural phenomenon. The eventual monitoring and forecasting of volcanic ash emissions should shed light on related processes such as charging in dust storms and industrial processes that involve granular materials.

Further reading
C Cimarelli *et al.* 2014 *Geology* **42** 79.

3D graphene from sugar

A new form of graphene, assembled into a 3D network, can be made from sugar bubbles. Building on the ancient culinary art of "blown sugar", Xuebin Wang and Yoshio Bando of Japan's World Premier International Center for Materials Nanoarchitectonics and colleagues made a syrup out of ordinary sugar and ammonium chloride, and heated it. This produced a glucose-based polymer called melanoidin, which was blown into bubbles by gases from the ammonium chloride. Syrup drained out of the bubble structure and continued heating left coherent structures made of graphene. The material is electrically conductive and mechanically robust (compressible to 80% its original size without loss of conductivity or stability) and inexpensive ($0.50 per gram) and can be used in graphene-based super capacitors.

Further reading
Wang *et al.* 2013 *Nature Communications* **4** 2905 doi: 10.1038/ncomms3905.

Eternal data archiving

A new approach to storing data promises high density with an effectively unlimited lifetime. Jingyu Zhang and colleagues at the University of Southampton used femtosecond laser nanostructuring of fused quartz to store data in an essentially 5D format: three co-ordinates for spatial location and two to describe the axis of the induced birefringence and its degree. Hundreds of terabytes of data can be stored per disk and at room temperature should last $3\times10^{20\pm1}$ years. Even at an elevated temperature of 462 K, the lifetime for data is expected to be comparable to the age of the universe, hence the claim that this could open a new era of "eternal data archiving". Writing speed is still slow – about 6 kB/s, but could be improved to 120 Mbit/s.

Further reading
J Zhang *et al.* 2014 *Phys. Rev. Lett.* **112** 033901.

Astrowatch

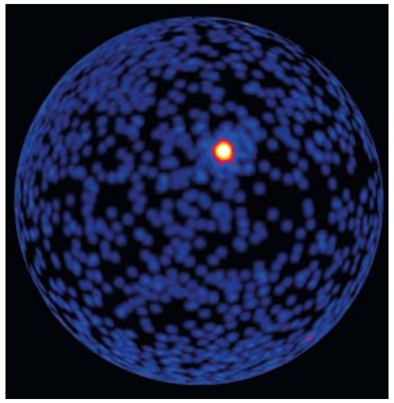
Compiled by Marc Türler, ISDC and Observatory of the University of Geneva, and University of Zurich

Record-setting GRB challenges theories

The very bright, relatively nearby gamma-ray burst (GRB) of 27 April 2013 – GRB 130427A – offers astronomers the most complete set of observational data of this phenomenon to date. While its general properties are in line with theory, the detection of extremely energetic gamma rays and other intriguing features challenges synchrotron-shock models.

GRBs are extremely powerful flashes of gamma rays arising about once per day from an arbitrary direction in the sky. Astronomers have known for about a decade that long GRBs are associated with the supernova explosion of massive stars (*CERN Courier* September 2003 p15). Since then, the dedicated Swift satellite has detected hundreds of gamma-ray bursts, therefore providing a huge data set of GRB observations (*CERN Courier* December 2005 p20). On 19 March 2008, Swift detected an extraordinarily bright burst, GRB 080319B, bright enough to see with the naked eye (*CERN Courier* June 2008 p12). However, it was the Gamma-ray Burst Monitor on board the Fermi Gamma-ray Space Telescope that gave the alert last year of the new record-setting GRB 130427A. The long duration and extreme brightness of this burst allowed the collection of an impressive data set from 58 ground- and space-based observatories, described and interpreted in four recent articles in *Science*.

Although slightly dimmer in the visible range than the one of 2008, the burst of 2013 was the brightest detected so far in the X-ray and gamma-ray range by the Swift and Fermi satellites. Maselli and collaborators point out that while the overall properties of GRB 130427A are similar to those of the most luminous, high-redshift GRBs, this time the burst was relatively nearby (redshift z = 0.34) – although still a quarter of the distance across the observable universe. The observed similarity suggests that there is no fundamental difference between recent, nearby GRBs and those of the early, remote universe. The detection of a supernova associated with this very bright GRB is further evidence that this relationship also holds for the most luminous GRBs, and strengthens the case for a common engine that powers all kinds of long GRBs.



A spherical projection of the sky around the north galactic pole during the extraordinary gamma-ray burst of 27 April 2013 (bright spot), as seen by the Fermi/LAT instrument at gamma-ray energies above 100 MeV. (Image credit: NASA/DOE/Fermi LAT Collaboration.)

This extraordinary burst is therefore an ideal laboratory for testing current models of GRBs. In the standard picture, the supernova explosion is accompanied by the formation of a black hole from the collapse of the massive star's core. The accretion of matter onto this rapidly spinning black hole then launches a jet that finds its way through the star's outer layers and into the surrounding gas. Shock waves propagating inside the jet and at its outer boundary would be at the origin of the prompt and afterglow emission, respectively.

One surprise is that the Large Area Telescope (LAT) on the Fermi satellite detected energetic gamma rays for 20 hours after the onset of the burst. Among them, two events of 73 GeV and 95 GeV are the highest-energy photons from a GRB ever recorded. The analysis of these data by the Fermi collaboration challenges the widely accepted model that this high-energy emission is of synchrotron origin. A natural additional emission component would be synchrotron self-Compton emission as Maselli and co-workers describe. In this process, the relativistic electron population in the jet both produces the synchrotron emission and then up-scatters these synchrotron photons to high energies via inverse-Compton interactions. While the overall understanding of GRBs seems to be valid, Preece and colleagues conclude, however, that it is difficult for any of the existing models to account for the observed spectral and temporal behaviours displayed by this rare GRB event.

Further reading

W T Vestrand *et al.* 2014 *Science* **343** 38.
M Ackermann *et al.* (Fermi collaboration) 2014 *Science* **343** 42.
A Maselli *et al.* 2014 *Science* **343** 48.
R Preece *et al.* 2014 *Science* **343** 51.

Picture of the month

An arrow points to a new supernova explosion in this image of the galaxy Messier 82 (M82). Located near the Big Dipper constellation, this spiral galaxy seen edge-on is famous for its starburst activity that ejects ionized gas, visible here as pink filaments. This active star formation would also be the source of the very-high-energy gamma rays detected from M82 by VERITAS (*CERN Courier* December 2009 p11). The interest of this picture of 23 January 2014, however, is the presence of the supernova SN 2014J. At a distance of 12 million light-years, it is the closest supernova of Type Ia in the past 40 years. This nearby event – detected just two days earlier by astronomers at the University College London Observatory – is not only a prime target for amateur astronomers, but also for numerous professional ground- and space-based observatories. (Image credit: Adam Block/Mount Lemmon SkyCenter/University of Arizona.)

CERN Courier Archive: 1971

A LOOK BACK TO CERN COURIER VOL. 11, MARCH 1971, COMPILED BY PEGGIE RIMMER

CERN NEWS

The A2: split or not split?

Whether the A2 meson has a split personality has been a source of controversy for the past five years. Missing mass experiments at CERN have indicated that the peak associated with the negative A2 meson at a mass of about 1300 MeV is split into two components. Measurements have been repeated with different experimental techniques and different apparatus and each time the A2 has come up clearly split. This observation was supported for the neutral A2 meson in another CERN experiment reported last autumn at the Kiev Conference.

However, a Berkeley bubble chamber experiment looking at the positive A2 meson saw no sign of splitting over a similar momentum range, and two new experiments looking at the negative A2 at much higher momentum have now come down on the side of no splitting.

The first result, announced at a CERN seminar last December, came from a CERN-Munich team. They used a negative pion beam of momentum 17.2 GeV/*c* from the proton synchrotron onto a hydrogen target to produce the A2 ($\pi^- + p \rightarrow A2^- + p$) and detected the A2 through its decay into a negative and a neutral kaon ($A2^- \rightarrow K^- + K^0_s$).

With a total of 1934 events in the mass range between 1000 and 2000 MeV there is no sign of A2 splitting.

A result from Brookhaven emerged at the American Physical Society in February to support this conclusion. This team studied exactly the same interaction sequence, using a 20.3 GeV/*c* pion beam from the AGS. With 564 events in the mass region 1200 to 1400 GeV, there is no splitting of the A2.

At the Kiev Conference A2 splitting was taken as well backed by experimental evidence and the problem was to find the theoretical explanation. Now it looks probable that the A2 will join the spin 2 multiplet as a single broad resonance and the problem is to understand the source of the narrow peaks found in the missing mass experiments.

● Compiled from texts on pp63–64.

AROUND THE LABS

Element 112 at Rutherford

A team at the Rutherford Laboratory may have first evidence for the existence of the element with atomic number 112.

Generally speaking, the more mutually repelling protons there are in a nucleus, the more unstable the element (but see later), and the heavier the element the more neutrons there are in its nucleus, proportionally, to ensure stability.

"Naturally occurring" elements stretch up to uranium, usually found with 92 protons and 146 neutrons. Creating heavier "transuranium" elements means producing nuclei containing more protons and still more neutrons. Such elements live for a comparatively short time before decaying, usually by fission or alpha emission.

The most fruitful production technique has been to bombard heavy nuclei with energetic heavy ions that can enter and add particles to the nuclei. A second technique is to expose heavy nuclei to large doses of neutrons that penetrate more easily. Once installed, a neutron can beta decay into a proton, converting the nucleus to that of a higher element.

In some nuclei protons and neutrons pair-off so well that the configuration is particularly stable. The "magic" numbers giving this stability are 2, 8, 28, 50, 82, 126. For example, the "doubly magic" lead nucleus, with 82 protons and 126 neutrons, is exceptionally stable.

It was predicted about three years ago that the nucleus with 114 protons and 184 neutrons might be of high stability. Elements close to it are also expected to have some very stable isotopes. The Berkeley Super-Hilac and other heavy ion accelerator projects aim to reach this transuranic "island of stability".

At the Rutherford Lab, A Marinov suggested that in targets bombarded with high-energy protons, an incoming proton could bounce a target nucleus forward with sufficient energy to crash into another nucleus producing nuclei of very heavy elements.

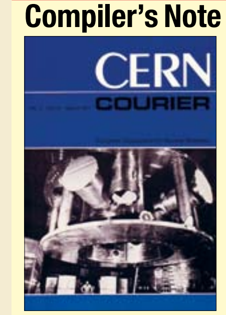
Two tungsten targets, element 74, which had been bombarded with 24 GeV protons at the CERN PS, were transported to Rutherford. Tungsten nuclei recoil energies were calculated to exceed the potential barrier of about 1 GeV between tungsten nuclei, so it was likely that nuclei often coalesced, with particle spill-off producing a whole range of transuranic elements. If formed, the longer-lived ones, such as those around element 114, might be detectable later.

Elements of radically different nuclear composition can exhibit similar chemical behaviour because chemical properties depend only on how electrons populate the outer fringe of the atom. In particular, element 112 is expected to behave chemically somewhat like mercury. So the targets were subjected to some intricate chemistry to isolate mercury-like elements, and the samples were studied for signs of fission and alpha emission. Covering samples with polycarbonate films yielded about 90 detected fission fragments in 37 days, and alpha particles of 6.73 MeV were observed, in the energy range predicted for element 112 and not clearly associated with any other known decay.

Obviously these results need amplifying and checking before the conclusion is completely accepted. It is nevertheless a thoughtful and provocative piece of research.

● Compiled from texts on pp70–71.

Compiler's Note



In science, seeing is not necessarily believing, especially without understanding. The split A2 was not understood, per se, and by the time of the 1972 Meson Spectroscopy Conference it had been abandoned. Understanding, however, enables scientists to postulate the existence of things not yet seen. It took about 40 years before various "sightings" of the transuranic element 112 passed a set of international criteria to become officially recognized as copernicium (*CERN Courier* September 2010 p7). It took somewhat longer, almost a half century, before the predicted Higgs boson was finally observed and accepted as reality.

ALICE: is cold nuclear matter really cold?

Some unexpected results at the LHC could hint at the formation of a quark–gluon plasma in proton–lead collisions, as this review from the ALICE collaboration explains.

In September 2012, the LHC provided proton–lead (pPb) collisions for the first time, two years after its heavy-ion collisions opened a new chapter in exploration of the properties of the deconfined, chirally symmetrical state of matter known as quark–gluon plasma, or QGP (*CERN Courier* October 2013 p17). Until then, measurements in lead–lead (PbPb) collisions had been typically compared with the corresponding proton–proton (pp) results to assess the properties of QGP. The strategy proved to be successful but remained incomplete. Indeed, within such an approach, the initial wave function of the colliding nuclei is not taken into account. This consideration was the primary motivation for including the measurements in pPb collisions as part of the heavy-ion programme at the LHC, with the expectation of being able to disentangle effects arising from the structure of the initial state of the collision – often dubbed "cold nuclear matter" effects – from the final-state effects related to the medium created, presumably, only in PbPb collisions.

In addition, understanding the structure of the initial state is interesting in its own right, because at the LHC energy, experiments probe the structure of the nucleus in a novel and unexplored QCD regime of very low values of the longitudinal parton-momentum fraction ($x < 10^{-3}$). In this kinematic region, the extremely high gluon density is expected to saturate by means of strongly non-linear coherent processes, leading theorists to predict the existence of yet another pre-collision state of matter – the so-called colour glass condensate (CGC).

ALICE collected data from pPb collisions at the LHC during both the short pilot run in September 2012 (*CERN Courier* November 2012 p6) and the longer high-luminosity run in January and February 2013 (*CERN Courier* March 2013 p5). The two-in-one design of the LHC magnets imposes the same magnetic rigidity for the two beams, necessitating an asymmetrical set-up in beam energy for pPb collisions. So in these runs, the energy in the nucleon–nucleon centre-of-mass system was $\sqrt{s_{NN}} = 5.02$ TeV, with the centre of mass shifted in the direction of the proton beam by about half a unit in rapidity with respect to the laboratory system.

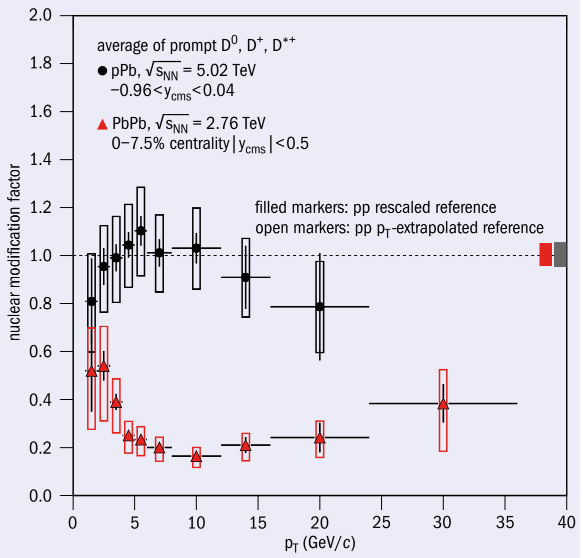


Fig. 1. The nuclear-modification factor, which compares data with pp collisions, for charm mesons in pPb (preliminary result) and PbPb collisions, as measured by ALICE.

The results from the basic control measurements, the charged-particle multiplicity density and transverse-momentum spectrum, were in agreement with expectations from theoretical models that incorporate present knowledge of the function describing the longitudinal distribution of partons inside the nucleus. In addition, when compared with the results obtained for pp collisions at 2.76 and 7 TeV, on one hand the charged-particle multiplicity in pPb collisions was found to scale roughly with the mean number of nucleons participating in the collision, as expected for particle production through soft processes. On the other hand, the particle spectrum at large transverse momenta – beyond 3–4 GeV/c – was found to scale with the mean number of binary nucleon–nucleon collisions, as expected for particle production through hard processes (*CERN Courier* December 2012 p6). Extending this latter measurement to charged jets and charmed mesons (figure 1) revealed no deviation from binary nucleon–nucleon scaling outside the large experimental uncertainties. The above observations confirm that the suppression of high transverse-momenta hadrons and jets observed in central PbPb collisions can be attributed to a ▷

final-state effect, namely, the energy loss experienced by partons traversing the medium created in these collisions.

As figure 2 shows, the measured rapidity distribution of the J/ψ charmonium state in pPb collisions, when compared with that measured in pp collisions, exhibits a moderate suppression in the forward hemisphere (positive values of rapidity, in the direction of the proton beam), while there is no suppression and even a slight enhancement in the backward hemisphere (negative values of rapidity, in the direction of the lead beam). These results can be well described by models that invoke the cold-nuclear-matter effects only and seem to disfavour the CGC-based models.

The first surprise came from the study of two-particle correlations in high-multiplicity pPb events. A surprising near-side, long-range (elongated in pseudorapidity) correlation, forming a ridge-like structure observed in high-multiplicity pp collisions, was also found in high-multiplicity pPb collisions, but with a much larger amplitude (*CERN Courier* January/February 2013 p9). However, the biggest surprise came from the observation that this near-side ridge is accompanied by an essentially symmetrical away-side ridge, opposite in azimuth (*CERN Courier* March 2013 p6). This double ridge was revealed after the short-range correlations arising from jet fragmentation and resonance decays were suppressed by subtracting the correlation distribution measured for low-multiplicity events from the one for high-multiplicity events.

Similar long-range structures in heavy-ion collisions have been attributed to the collective flow of particles emitted from a thermalized system undergoing a collective hydrodynamic expansion. Early interactions produce pressure gradients that translate the spatial anisotropy in the overlapping region of the nuclei into an anisotropy in momentum space. This anisotropy can be characterized by means of the v_n (n = 2, 3, ...) coefficients of a Fourier decomposition of the single-particle azimuthal distribution.

Recently, the analysis has been extended to four-particle correlations, which have been proved in heavy-ion collisions to be much less sensitive to jet-related correlations. Again, the similarity with results obtained in PbPb collisions is striking: the v_2 harmonic coefficients measured in pPb are similar to the ones obtained in PbPb collisions at comparable event multiplicities, as is their transverse momentum dependence – a continuous increase up to a transverse momentum of 2–3 GeV/*c*, followed by a gradual decrease owing to the increasing contribution from the jet fragmentation. The latter effect arises because the harmonic coefficients measure the strength of the particle correlations with respect to a symmetry plane, while the jet fragments are expected to be only slightly correlated via energy losses to that plane, because they are not expected to participate in the collective motion of the system.

To test the possible presence of collective phenomena further, the ALICE collaboration has extended the two-particle correlation analysis to identified particles, checking for a potential mass ordering of the v_2 harmonic coefficients. Such an ordering in mass was observed in heavy-ion collisions, where it was interpreted to arise from a common radial boost – the so-called radial flow – coupled to the anisotropy in momentum space. Continuing the surprises, a clear particle-mass ordering, similar to the one observed in mid-central PbPb collisions (*CERN Courier* September 2013 p6), has been measured in high-multiplicity pPb collisions.

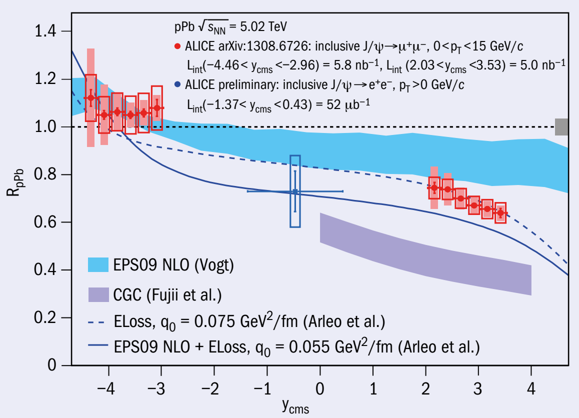


Fig. 2. The J/ψ nuclear-modification factor in pPb (preliminary results).

These similarities are not the only ones. By measuring the dependence on the event multiplicity of the identified-particle transverse-momentum spectra or the averaged transverse momentum (*CERN Courier* September 2013 p10), a significant hardening of the spectra has been observed with increasing multiplicity. Moreover, the hardening is found to be stronger for heavier particles. Such an observation is interpreted in PbPb collisions as a signature of radial flow. The blast-wave fit, with parameters associated with the kinetic freeze-out temperature and the mean transverse-expansion velocity, describes the shape of the particle spectra, as well as the v_2 coefficient (figure 3, p20).

The value and the multiplicity dependence of these two parameters are similar to the ones measured in PbPb collisions. Although models that consider a hydrodynamic evolution of the colliding system can describe this feature satisfactorily, an alternative explanation has been put forward: colour reconnection. This mechanism, implemented in the PYTHIA event generator, can be seen as a final-state interaction between outgoing partons originating from different hard-scattering processes and might result in effects that are qualitatively similar to particle-flow correlations.

The final surprise, so far, comes from the charmonium states. Whereas J/ψ production does not reveal any unexpected behaviour, the production of the heavier and less-bound (2S) state indicates a strong suppression (0.5–0.7) with respect to J/ψ, when compared with pp collisions. Is this a hint of effects of the medium? Indeed, in heavy-ion collisions, such a suppression has been interpreted as a sequential melting of quarkonia states, depending on their binding energy and the temperature of the QGP created in these collisions.

It is tempting to raise the question: is QGP formed in high-multiplicity pPb collisions?

Taking all of these observations together and in view of the astonishing similarities between pPb and PbPb ▷

Heavy ions

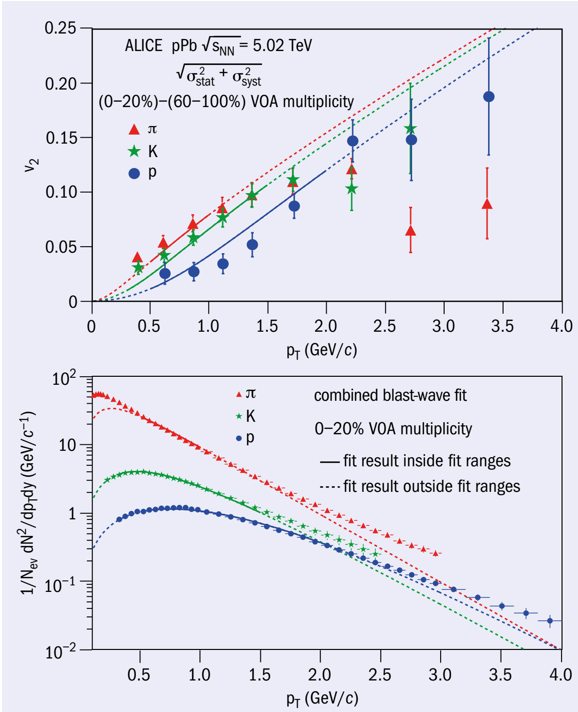


Fig. 3. Blast-wave fit of pion, kaon and proton transverse-momenta spectra (bottom) and v_2 coefficients (top).

collisions, it is tempting to raise the obvious question: is QGP formed in high-multiplicity pPb collisions? By considering the measured particle multiplicity and the small size of the colliding system, it can be deduced that the initial energy density in high-multiplicity pPb events exceeds the one measured in PbPb collisions, and therefore the critical value for the QGP phase transition. However, could such a small and short-lived system reach thermal equilibrium fast enough to form a QGP-like droplet?

Part of the answer comes from the measured properties of QGP. As the estimated ratio of shear viscosity to entropy is close to the quantum limit for a perfect liquid, it is possible to deduce a value of the mean free path of constituents inside QGP that is several times smaller than the typical pPb system size of 1–2 fm. However, other explanations of the origin of the observed collective-like phenomena cannot be excluded. Rather as the colour-reconnection mechanism can explain the observed hardening of the transverse-momentum spectra with multiplicity, other models developed within the CGC framework can describe the dependence of two-particle correlations on the event multiplicity and the identified particle transverse momentum, but they are less successful in describing results from four-particle correlations and identified-particle correlations. Of course, this does not exclude the melting of CGC during the initial stage of the collision, followed by thermalization of the system and hydrodynamic flow.

To summarize this first pPb measurement campaign, expected results were widely accompanied by unanticipated observations. Among the expected results is the confirmation that proton–nucleus collisions provide an appropriate tool to study the partonic structure of cold nuclear matter in detail. The surprises have come from the similarity of several observables between pPb and PbPb collisions, which hint at the existence of collective phenomena in pPb collisions with high particle multiplicity and, eventually, the formation of QGP.

A deeper insight into the dynamics of pPb collisions can come from exclusive measurements classifying events according to their impact parameter and extracting the physics observables in intervals of collision centrality. In PbPb collisions, the centrality estimators typically make use of the particle multiplicity or total transverse-energy measured in various pseudorapidity intervals, and the estimator value is then transformed into a number of binary nucleon–nucleon collisions through the Glauber model, which provides a classical representation of the initial geometry of the colliding system. In pPb collisions, the event classification into centrality intervals is strongly biased, owing to fluctuations of the measured particle multiplicity for a given number of binary nucleon–nucleon collisions.

In general, central (peripheral) events have larger (smaller) particle multiplicity per participating nucleon than average, the particle-production source being parton scattering. At LHC energies, such fluctuations are large because they are introduced by multi-parton interactions whose amount fluctuates strongly among events of similar centrality. Therefore the event classification using the conventional centrality estimators breaks the scaling of the measured particle production with the number of binary nucleon–nucleon collisions. This has been demonstrated by comparing the charged-particle spectra at mid-rapidity in centrality intervals defined by various centrality estimators available in ALICE.

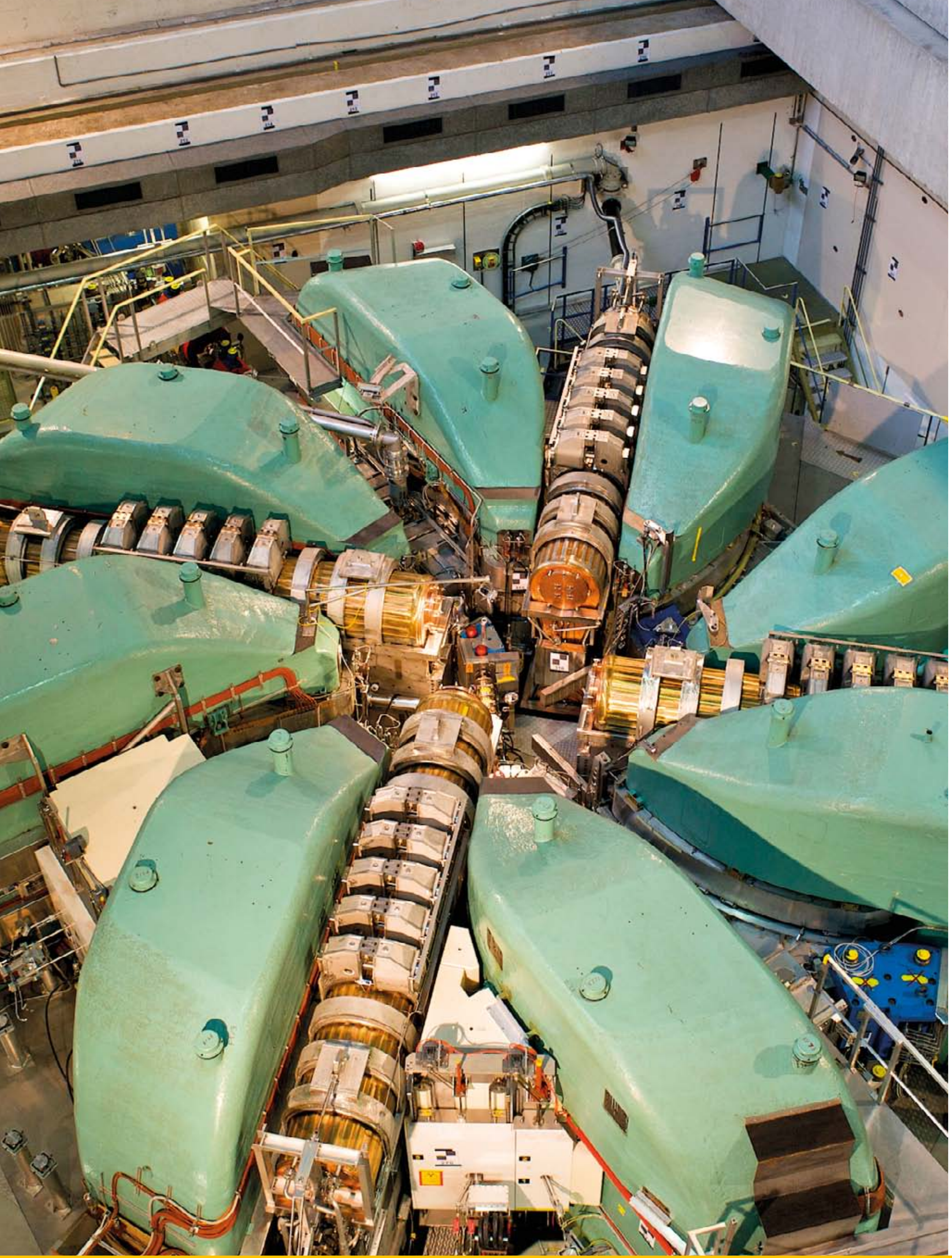
Nevertheless, if a proper centrality determination can be established, all of the above-mentioned physics observables will be studied in centrality intervals to answer in particular the question of whether the jet-quenching phenomenon is present in central pPb collisions. At the same time, while the LHC is being prepared for its second phase of operation, the ALICE collaboration continues to analyse the precious sample of pPb collision data already recorded.

Résumé

ALICE : la matière nucléaire froide est-elle vraiment froide ?

En septembre 2012, pour la première fois, des collisions proton-plomb ont eu lieu au LHC ; une exploitation proton-plomb de plus grande durée et de plus grande intensité a eu lieu en janvier-février 2013. L'expérience ALICE a permis de recueillir des données au cours des deux périodes d'exploitation. Outre les résultats attendus, de nombreuses observations inattendues ont été faites. Les surprises proviennent de similitudes de plusieurs observables entre collisions proton-plomb et collisions plomb-plomb au LHC. Ces similitudes pourraient indiquer l'existence de phénomènes collectifs dans les collisions proton-plomb avec forte multiplicité, et, finalement, la formation de l'état déconfiné de la matière connu sous le nom de plasma quark-gluon.

Cvetan Cheshkov, Institute de Physique Nucléaire de Lyon, Université Claude Bernard Lyon 1, on behalf of the ALICE collaboration.



Physics at the low-energy, high-precision frontier

A workshop at PSI focused on the physics of fundamental symmetries and interactions.

More than 180 physicists from around the world gathered at the Paul Scherrer Institut (PSI) last year for the 3rd workshop on the "Physics of fundamental Symmetries and Interactions" at low energies and the precision frontier – PSI2013. Broadly speaking, the focus was on high-precision experiments, with results complementary to those at the LHC, often covering a parameter space in physics beyond the Standard Model that is inaccessible to direct searches at the LHC or even at future colliders.

PSI's particle-physics laboratory fosters cutting-edge research using the unmatched high power of its 590 MeV, 2.2 mA proton cyclotron to produce the brightest low-momentum beams of muons and pions and, since 2011, ultracold neutrons. This environment set the scene for lively discussions on the latest results and the future direction of worldwide low-energy precision experiments. Among the many workshop contributions, there were several major topical areas of interest.

Fundamental physics probed with antiprotons and antihydrogen featured prominently, with recent results from experiments at CERN's Antiproton Decelerator. The now regular production of antihydrogen has moved these experiments closer to final physics measurements. Among the main goals are sensitive tests of CPT symmetry and measurements in antihydrogen spectroscopy, such as determination of the ground-state hyperfine splitting, together with tests of antihydrogen free fall. A recent result is the Penning-trap measurement by the ATRAP collaboration of the antiproton's magnetic moment to 5 ppm precision. A further highlight, involving Penning traps but with ordinary matter, is determination of the electron's mass with unprecedented precision by the MPI-Heidelberg group, achieving an order-of-magnitude improvement.

Many presentations covered experiments using cold (CN) or ultracold (UCN) neutrons. A full session was devoted to the neutron lifetime and worldwide progress on improving its precision, to resolve the significant outstanding discrepancy between results from neutron-storage experiments and those using beams. For the latter, a new result from the National Institute of Standards and Technology in the US was presented, consolidating the existing discrepancy.

Neutron-decay parameters and spin correlations of the decay particles are sensitive to physics beyond the Standard Model. Competing CN and UCN experiments using improved experimental techniques such as precision neutron polarimetry at the 100 ppm level were presented, with future plans for UCNs at Los Alamos National Laboratory (LANL) and the Proton Electron Radiation Channel project at the FRM II neutron source at the Technische Universität München. Other parity-violation experiments were also discussed, with a new result for neutron capture on hydrogen by the NPDG experiment at the Spallation Neutron Source (SNS) at Oak Ridge, trapped radium ions at KVI Groningen, and neutron spin rotation in helium.

UCN production with new-generation sources – either in existence or under construction – was extensively covered, including the use of superfluid helium (at Institut Laue–Langevin (ILL) and TRIUMF) and solid deuterium (Mainz, LANL and PSI) as superthermal converters. UCN densities are steadily increasing, despite experimental and technical difficulties that have slowed down the expected progress. The main thrust for these high-intensity UCN sources comes from the search for a permanent electric dipole moment (EDM) of the neutron. Because it is the focus of an experiment at PSI, there was intensive discussion on this topic at the workshop. Several talks elaborated on efforts to search for the neutron EDM by international collaborations at various institutions. These are mainly based on UCN-storage measurements that employ either Ramsey's Oscillatory Field method (at ILL, SNS, PSI, the Petersburg Nuclear Physics Institute, TRIUMF, Osaka University and FRM II) or crystal diffraction (at ILL).

Complementary atomic (Fr, Ra, Xe) and molecular (YbF, ThO) EDM searches have even higher experimental sensitivities, but sometimes suffer from being more difficult to interpret in terms of the fundamental EDMs. Diamagnetic atoms are usually interpreted in terms of searches for nuclear EDMs, whereas measurements in polar molecules and paramagnetic atoms give limits on the electron EDM. However, the workshop was a little too early to see the result of the new ThO experiment ACME, by a Harvard/Yale University group, which appeared shortly afterwards. Proposed storage-ring-based EDM measurements with protons and deuterons are also being pursued actively. ▷

The main isochronous cyclotron of PSI's high-intensity proton accelerator complex (HIPA) routinely delivers a 2.2 mA proton beam current at 590 MeV and is the basis for high-precision particle-physics experiments that employ muons, pions and neutrons. (Image credit: PSI.)

PSI2013


The double-trunked mammoth in front of the auditorium building, posing together with the workshop participants, is a "phantastic beast" of the late Swiss artist Bruno Weber. (Image credit: S Ritt.)

Common to all of the EDM searches are the many challenging experimental difficulties, especially in terms of magnetic shielding and the control and measurement of the magnetic field. Presentations from the theoretical side underlined that EDM studies in different systems are complementary and necessary in helping to identify the underlying models of CP or T violation. Also in this context, recent results on CP violation were presented from the NA62 experiment at CERN, on the kaon system, and from LHCb at the LHC.

UCNs also allow study of the quantization of gravitational bound states of the neutron, which are sensitive to non-Newtonian gravity and hypothetical extra forces, mediated by, for example, axions, axion-like particles, or chameleons. Such forces can also be probed in clock-comparison experiments, as explained at the workshop for the ^{3}He/^{129}Xe case. These are sensitive to possible Lorentz violations, which can be accommodated in the framework of the so-called Standard Model Extension (SME). In the SME, Lorentz violation stems from an underlying background field in the universe, resulting, for example, in day/night or annual variations of fundamental parameters. Recently calculated effects in neutron decay, as well as in muonium and positronium spectroscopy, were also discussed, with experimental efforts.

Charged-lepton flavour violation was another key topic where increasing worldwide efforts are under way. Lepton flavour violation involving muons is predicted by various models that go beyond the Standard Model, at levels that might be within reach of the next generation of experiments. Nevertheless, major progress is needed, both in experimental techniques and in increased muon-beam intensities, and is being pursued actively.

The international PSI-based MEG collaboration presented its new limit of 5×10^{-13} on the $\mu \to e\gamma$ branching ratio. The project to search for the decay $\mu \to 3e$ at a sensitivity level of 10^{-16} was presented by the Mu3e collaboration. Impressive efforts towards the construction of the Muon Campus at Fermilab were also shown, with the goal of a new, more precise $(g-2)_{muon}$ measurement to help solve or confirm the present discrepancy with the Standard Model calculation. There are also plans to search for $\mu \to e$ conversion within Project-X, at a sensitivity of 10^{-17} and beyond. Similar efforts in Japanese projects that are ongoing at Osaka University and the Japan Proton Accelerator Research Complex (J-PARC) were also detailed. These involve huge efforts in the muon sector towards, for example, $\mu \to e$ conversion and muon g–2 experiments. The progress shown at J-PARC following repairs of the extensive earthquake damage was impressive.

The new result on the pseudoscalar coupling between the muon and the proton from the MuCAP experiment at PSI was presented and discussed, finally solving a long-standing puzzle and providing the first precise value of this Standard Model parameter. Interpretations within recent calculations based on effective field theory were presented, together with relevant ongoing precision measurements in the deuterium system.

In the light of the current construction of the free-electron laser – SwissFEL – at PSI, the possible use of such high photon-intensities or electron beams for particle-physics experiments attracted much interest, for example in using high-intensity lasers for "light shining through the wall experiments", which search for weakly interacting sub-electronvolt particles. The final session of the workshop – held with the detector workshop of the Swiss Institute of Particle Physics, CHIPP – provided an overview of state-of-the-art detector technology, which is under development to cope with future high-intensity experiments.

Aside from fundamental science, the Hochrhein Bigband jazz concert delighted participants, as did the workshop dinner featuring a "fundamental classic" of Swiss cusine – raclette. A workshop summary of the year 2034 provided an amusing outlook from a theoretician's point of view of what might be important in particle physics 20 years from now. In the meantime, there was great encouragement on the part of all participants to meet again at PSI for PSI2016.

Further reading

For more information on PSI2013, visit www.psi.ch/psi2013/.

Résumé

Physique haute précision aux limites des basses énergies

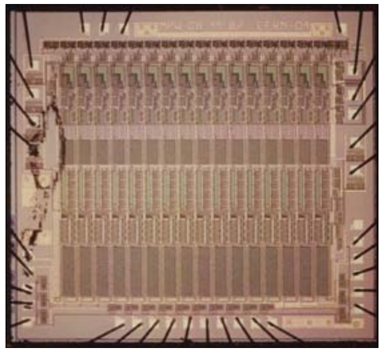
Des physiciens du monde entier se sont réunis à l'Institut Paul Scherrer l'année dernière à l'occasion de PSI2013, le 3e atelier sur la physique des symétries fondamentales et des interactions aux basses énergies et aux limites de la précision. De façon générale, l'accent a été mis sur les expériences de haute précision : expériences sur l'antihydrogène, autres expériences utilisant des neutrons ultra-froids, ou encore mesures de modes de désintégration rares. Les résultats présentés étaient complémentaires de ceux produits au LHC, couvrant souvent un espace de paramètres en physique au-delà du Modèle standard inaccessible aux recherches directes réalisables au LHC ou même auprès de futurs collisionneurs.

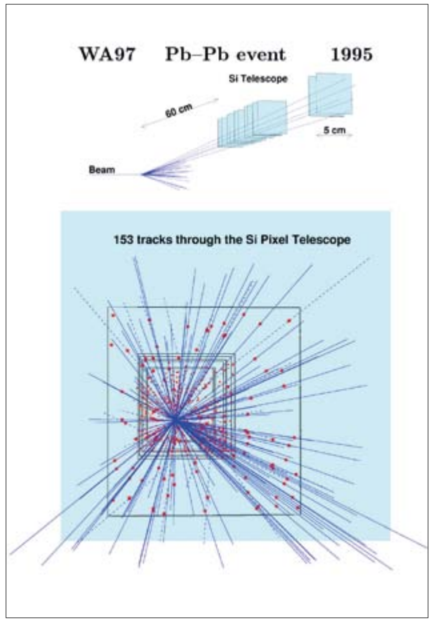
Klaus Kirch, **Bernhard Lauss** and **Stefan Ritt**, PSI.

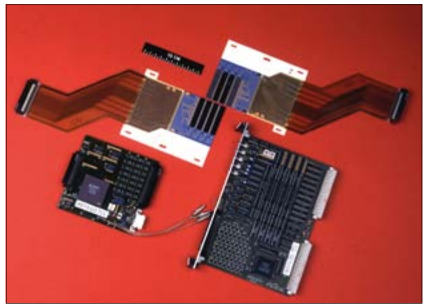
CERN Courier March 2014

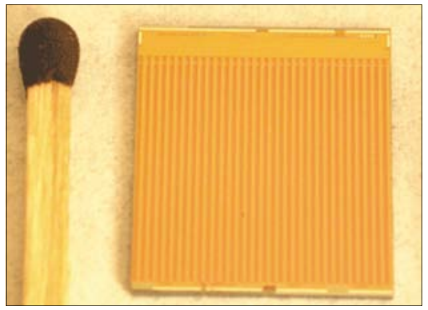
60 years of CERN

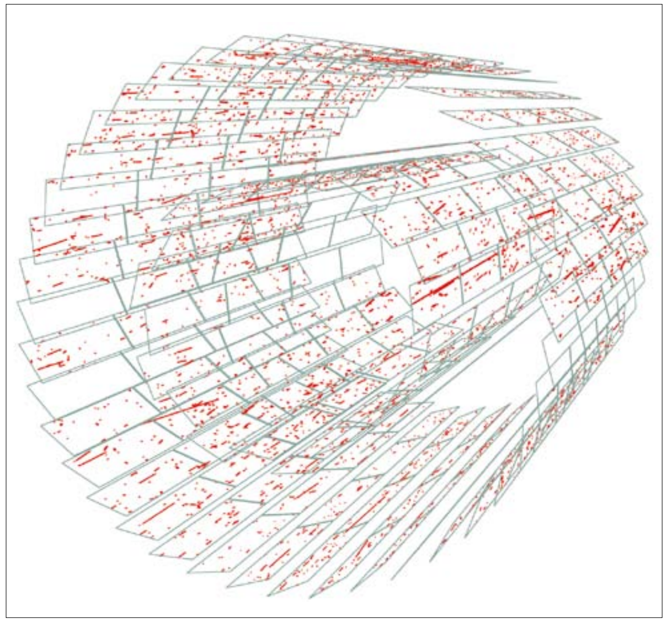
Microelectronics at CERN: from infancy to maturity











Two decades of microelectronics at CERN – enabled by the LAA project. In 1988, the AMPLEX multiplexed read-out chip (top left) allowed UA2 to fit a silicon-pad detector (bottom left) in the 9 mm gap around the beam pipe (Image credit: C Gößling, TU Dortmund). Hybrid pixel devices, with a read-out chip "bump bonded" to the detector (top centre), were used in WA97 in the mid-1990s. By 2002, CERN had developed a bump-bonded 8000-channel pixel array (bottom centre) for the ALICE silicon-pixel detector at the LHC, which in 2008 recorded muon tracks produced in the nearby beam dump during the first injection tests (right).

The start of the LAA project in 1986 propelled electronics at CERN into the era of microelectronics, and laid crucial foundations for the success of the LHC experiments.

When the project for the Large Electron–Positron (LEP) collider began at CERN in the early 1980s, the programme required the concentration of all available CERN resources, forcing the closure not only of the Intersecting Storage Rings and its experiments, but of all the bubble chambers and several other fixed-target programmes. During this period, the LAA detector R&D project was approved at the CERN Council meeting in December 1986 as "another CERN programme of activities" (see box) opening a door to initiate developments for the future. A particular achievement of the project was to act as an incubator for the development of microelectronics at CERN, together with the design of silicon-strip and pixel detectors – all of which would become essential ingredients for the superb performance of the experiments at the LHC more than two decades later.

The start of the LAA project led directly to the build-up of know-how within CERN's Experimental Physics Facilities Division, with the recruitment of young and creative electronic engineers. It also enabled the financing of hardware and software tools, as well as the training required to prepare for the future. By 1988, an electronics design group had been set up at CERN, dedicated to the silicon technology that now underlies many of the high-performing detectors at the LHC and in other experiments. Miniaturization to sub-micrometre scales allowed many functions to be compacted into a small volume in sophisticated, application-specific integrated circuits (ASICS), generally based on complementary metal-oxide-silicon (CMOS) technology. The resulting microchips incorporate analogue or digital memories, so selective read-out of only potentially useful data can be used to reduce the volume of data that is transmitted and analysed. This allows the recording of particle-collision events at unprecedented rates – the LHC experiments register 40 million events per second, continuously.

Last November, 25 years after the chip-design group was set up, some of those involved in the early days of these developments – including Antonino Zichichi, the initiator of LAA – met at CERN to celebrate the project and its vital role in establishing microelectronics at CERN. There were presentations from Erik Heijne and Alessandro Marchioro, who were among the founding members of the group, and from Jim Virdee, who is one of the founding fathers of the CMS experiment at the LHC. Together, they recalled the birth and gradual growth to maturity of microelectronics at CERN.

The beginnings

The story of advanced ASIC design at CERN began around the time of UA1 and UA2, when the Super Proton Synchrotron was operating as a proton–antiproton collider, to supply enough interaction energy for discovery of the W and Z bosons. In 1988, UA2 became, by chance, the first collider experiment to exploit a silicon detector with ASIC read-out. Outer and inner silicon-detector arrays were inserted into the experiment to solve the difficulty of identifying the single electron that comes from a decay of the W boson, close to the primary interaction vertex. The inner silicon-detector array with small pads could be fitted in the 9 mm space around the beam pipe, thanks to the use of the AMPLEX – a fully fledged, 16-channel 3-μm CMOS chip for read-out and signal multiplexing.

The need for such read-out chips was triggered by the introduction of silicon microstrip detectors at CERN in 1980 by Erik Heijne and Pierre Jarron. These highly segmented silicon sensors allow micrometre precision, but the large numbers of parallel sensor elements have to be dealt with by integrated on-chip signal processing. To develop ideas for such detector read-out, in the years 1984–1985 Heijne was seconded to the University of Leuven, where the microelectronics research facility had just become the Interuniversity MicroElectronics Centre (IMEC). It soon became apparent that CMOS technology was the way ahead, and the experience with IMEC led to Jarron's design of the AMPLEX.

(Earlier, in 1983, a collaboration between SLAC, Stanford University Integrated Circuits Laboratory, the University of Hawaii and Bernard Hyams from CERN had already initiated the design of the "Microplex" – a silicon-microstrip detector read-out chip using nMOS, which was eventually used in the MARK II experiment at SLAC in the summer of 1990. The design was done in Stanford by Sherwood Parker and Terry Walker. A newer iteration of the Microplex design was used in autumn 1989 for the microvertex detector in the DELPHI experiment at LEP.)

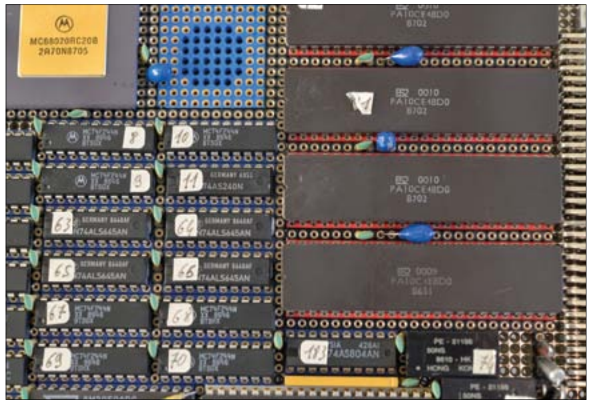
Heijne and Jarron were keen to launch chip design at CERN, as was Alessandro Marchioro, who was interested in developing digital microelectronics. However, finances were tight after the approval of LEP. With the appearance of new designs, the tools and methodologies developed in industry had to be adopted. For example, performing simulations was better than the old "try-and-test technique" of wire wrapping, but this required the appropriate software, including licences and training. The LAA project came at just the right time, allowing the chip-design group to start work in the autumn of 1988, with a budget for workstations, design software and analysis equipment – and crucially, up to five positions for chip-design engineers, most of whom remain at CERN to this day.

On the analogue side, there were three lines to the proposed research programme within LAA: silicon-microstrip read-out, a silicon micropattern pixel detector and R&D on chip radiation-hardness. The design of the first silicon-strip read-out chip at CERN – dubbed HARP for Hierarchical Analog Readout Processor – moved ahead quickly. The first four-channel prototypes were already received in 1988, with work such as the final design verification and layout check still being done at IMEC.

The silicon micropattern pixel detector, with small pixels ▷

The LAA

The LAA programme, proposed by Antonino Zichichi and financed by the Italian government, was launched as a comprehensive R&D project to study new experimental techniques for the next step in hadron-collider physics at multi-tera-electron-volt energies. The project provided a unique opportunity for Europe to take a leading role in advanced technology for high-energy physics. It was open to all physicists and engineers interested in participating. A total of 40 physicists, engineers and technicians were recruited, and more than 80 associates joined the programme. Later in the 1990s, during the operation of LEP for physics, the programme was complemented by the activities overseen by CERN's Detector R&D Committee.



The first digital ASIC designed at CERN – the four large chips visible to the right.

in a 2D matrix, required integration of the sensor matrix and the CMOS read-out chip, either in the same silicon structure (monolithic) or in a hybrid technology with the read-out chip "bump bonded" to each pixel. Such a chip was developed as a prototype at CERN in 1989 in collaboration with Eric Vittoz of the Centre Suisse d'Electronique et de Microtechnique and his colleagues at the École polytechnique fédérale de Lausanne. While it turned out that this first chip could not be bump bonded, it successfully demonstrated the concept. In 1991, the next pixel-read-out chip designed at CERN was used in a three-unit "telescope" to register tracks behind the WA94 heavy-ion experiment in the Omega spectrometer. This test convinced the physicists to propose an improved heavy-ion experiment, WA97, with a larger telescope of seven double planes of pixel detectors. This experiment not only took useful data, but also proved that the new hybrid pixel detectors could be built and exploited.

Research on radiation hardness in chips remained limited within the LAA project, but took off later with the programme of the Detector Research and Development Committee (DRDC) and the design of detectors for the LHC experiments. Initially, it was more urgent to show the implementation of functioning chips in real experiments. Here, the use of AMPLEX in UA2 and later the first pixel chips in WA97 were crucial in convincing the community.

In parallel, components such as time-to-digital converters (TDCs) and other Fastbus digital-interface chips were successfully developed at CERN by the digital team. The new simulation tools purchased through the financial injection from the LAA project were used for modelling real-time event processing in a Fastbus data-acquisition system. This was to lead to high-performance programmable Fastbus ASICs for data acquisition in the early 1990s. Furthermore, a fast digital 8-bit adder-multiplier with a micropipelined architecture for correcting pedestals, based on a 1.2 µm CMOS technology, was designed and used in early 1987. By 1994, the team had designed a 16-channel TDC for the NA48 experiment, with a resolution of 1.56 ns, which could be read out at 40 MHz. The LAA had well and truly propelled the engineers at CERN into the world of microtechnology.

Timepix chip from CERN in a USB stick developed at IEAP, Czech Technical University, Prague. (Image credit: IEAP CTU.)

The challenge for the LHC

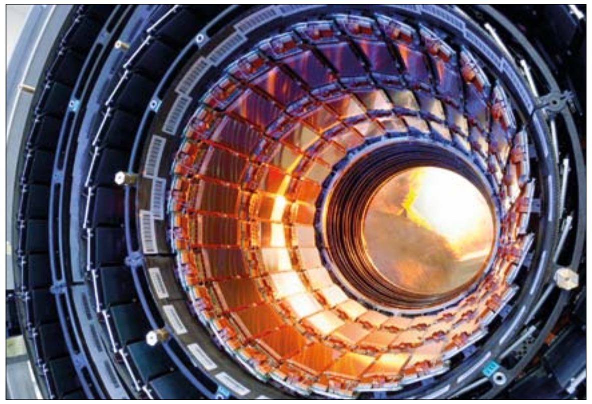
A critical requirement for modern high-energy-physics detectors is to have highly "transparent" detectors, maximizing the interaction of particles with the active part of the sensors while minimizing similar interactions with auxiliary material such as electronics components, cables, cooling and mechanical infrastructure – all while consuming absolute minimum power. Detectors with millions of channels can be built only if each channel consumes milliwatts of power. In this context, the developments in microelectronics offered a unique opportunity, allowing the read-out system of each detector to be designed to provide optimal signal-to-noise characteristics for minimal power consumption. In addition, auxiliary electronics such as high-speed links and monitoring electronics could be highly optimized to provide the best solution for system builders.

However, none of this was evident when thoughts turned to experiments for the LHC. The first workshop on the prospects for building a large proton collider in the LEP tunnel took place in Lausanne in 1984, the year following the discovery of the W and Z bosons by UA1 and UA2. A prevalent saying at the time was "We think we know how to build a high-energy, high-luminosity hadron collider – we don't have the technology to build a detector for it." Over the next six years, several seminal workshops and conferences took place, during the course of which the formidable experimental challenges started to appear manageable, provided that enough R&D work could be carried out, especially on detectors.

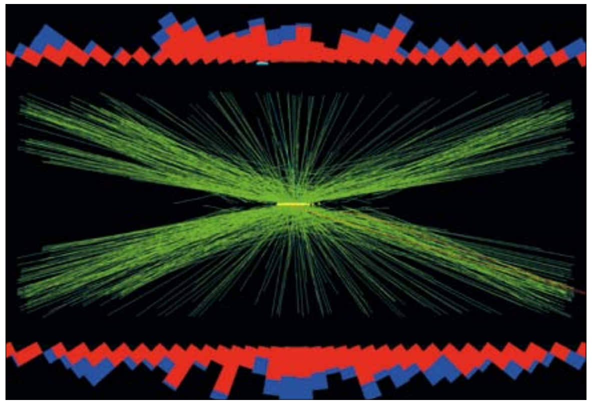
The LHC experiments needed special chips with a rate capability compatible with the collider's 40 MHz/25 ns cycle time and with a fast signal rise time to allow each event to be uniquely identified. (Recall that LEP ran with a 22 µs cycle time.) Thin – typically 0.3 mm – silicon sensors could meet these requirements, having a dead time of less than 15 ns. With sub-micron CMOS technology, front-end amplifiers could also be designed with a recovery time of less than 50 ns, therefore avoiding pile-up problems.

Thanks to the LAA initiative and the launch in 1990 by CERN of R&D for LHC detectors, overseen by the DRDC, technologies were identified and prototyped that could operate well in the harsh conditions of the LHC. In particular, members of the CERN microelectronics group pioneered the use of special full custom-design techniques, which led to the production of chips capable of withstanding the extreme radiation environment of the experiments while using a commercially available CMOS process. The first full-scale chip developed using these techniques is the main building block of the silicon-pixel detector in the ALICE experiment. Furthermore, in the case of CMS, the move to sub-micron 0.25-µm CMOS high-volume commercial technology for producing radiation-hard chips enabled the front-end read-out for the tracker to be both affordable and delivered on time. This technology became the workhorse for the LHC and has been used since for many applications, even where radiation tolerance is not required.

60 years of CERN



The central part of the CMS tracker barrel – just some of the 200 m² of silicon in the complete detector. Note the person visible partially through the centre.



The power of silicon: as many as 78 vertices are reconstructed in this event in CMS, recorded during a special high-pile-up run at the LHC in 2012.

An example of another area that benefited from an early launch, assisted by the LAA project, is optical links. These play a crucial role in transferring large volumes of data, an important example being the transfer from the front ends of detectors that require one end of the link to be radiation hard – again, a new challenge.

Today, applications that require a high number of chips can profit from the increase in wafer size, with many chips per wafer, and low cost in high-volume manufacturing. This high level of integration also opens new perspectives for more complexity and intelligence in detectors, allowing new modes of imaging.

Looking ahead

Many years after Moore's law was suggested, miniaturization still seems to comply with it. There has been continuous progress in silicon technology, from 10 µm silicon MOS transistors in the 1970s to 20 nm planar silicon-on-insulator transistors today. Extremely complex FinFET devices promise further downscaling to 7 nm transistors. Such devices will allow even more intelligence in detectors. The old dream of having detectors that directly provide physics primitives – namely, essential primary information about the phenomena involved in the interaction of particles with matter – instead of meaningless "ADC counts" or "hits" is now fully within reach. It will no longer be necessary to wait for data to come out of a detector because new technology for chips and high-density interconnections will make it possible to build in direct vertex-identification, particle-momenta evaluation, energy sums and discrimination, and fast particle-flow determination.

Some of the chips developed at CERN – or the underlying ideas – have found applications in materials analysis, medical imaging and various types of industrial equipment that employ radiation. Here, system integration has been key to new functionalities, as well as to cost reduction. The Medipix photon-counting chip developed in 1997 with collaborators in Germany, Italy and the UK is the ancestor of the Timepix chip that is used today, for example, for dosimetry on the International Space Station and in education projects. Pixel-matrix-based radiation imaging also has many applications, such as for X-ray diffraction. Furthermore, some of the techniques that were pioneered and developed at CERN for manufacturing chips sufficiently robust to survive the harsh LHC conditions are now adopted universally in many other fields with similar environments.

Looking ahead to Europe's top priority for particle physics, exploitation of the LHC's full potential until 2035 – including the luminosity upgrade – will require not only the maintenance of detector performance but also its steady improvement. This will again require a focused R&D programme, especially in microelectronics because more intelligence can now be incorporated into the front end.

Lessons learnt from the past can be useful guides for the future. The LAA project propelled the CERN electronics group into the new world of microelectronic technology. In the future, a version of the LAA could be envisaged for launching CERN into yet another generation of discovery-enabling detectors exploiting these technologies for new physics and new science.

Résumé

La microélectronique au CERN : de la petite enfance à l'âge adulte

Le programme LAA, proposé par Antonino Zichichi et financé par le gouvernement italien, a été lancé comme projet R&D complet visant à l'étude de nouvelles techniques expérimentales pour la prochaine étape de la physique des collisionneurs de hadrons aux énergies de l'ordre de plusieurs téra-électron-volts. Le démarrage du projet LAA a conduit directement à l'accumulation d'un savoir-faire au CERN, avec le recrutement de jeunes talents en génie électronique. Cela a permis le développement au CERN de la microélectronique, qui, avec la conception des détecteurs à rubans de silicium et à pixels, devait jouer un rôle essentiel dans la magnifique performance des expériences au LHC plus de vingt ans plus tard.

Horst Wenninger, CERN, leader of the Experimental Physics Facilities Division at the time the decision was taken to incorporate the LAA project into the division.

Antigravity matters at WAG 2013

Physicists met in Bern to review experimental and theoretical aspects of the interaction of antimatter with gravity.

Participants at the WAG 2013 meeting. (Image credit: AEC.)

Aristotle said that "An iron ball of one hundred pounds, falling from a height of one hundred cubits [about 5.2 m], reaches the ground before a one-pound ball has fallen a single cubit." Galileo Galilei replied, "I say that they arrive at the same time." The universality of free fall illustrated by the latter's legendary experiment at the tower of Pisa was formulated by Isaac Newton in his *Principia* and became, with Albert Einstein, the weak equivalence principle (WEP): the motion of any object under the influence of gravity does not depend on its mass or composition. This principle is the cornerstone of general relativity.

The WEP has been verified to incredible precision by dropping experiments and Eötvös-type torsion balances, the latter reaching an amazing accuracy of one part in 10^{13}. The acceleration of the Earth and the Moon towards the Sun has also been determined to the same accuracy by measuring the transit time of laser pulses between the planet and the reflectors left on the Moon by the Apollo and Soviet space missions. But does the WEP also hold for antimatter for which no direct measurement has been performed, in particular for antimatter particles such as positrons or antiprotons? Or does antimatter even fall up?

The purpose of the 2nd International Workshop on Antimatter and Gravity, which took place on 13–15 November, was to review the experimental and theoretical aspects of antimatter interaction with gravity. The meeting was hosted by the Albert Einstein Center for Fundamental Physics of the University of Bern, following the success of the first workshop held in 2011 at the Institut Henri Poincaré in Paris. The highlights are summarized here.

Free-fall experiments with charged particles are notoriously difficult because they must be carefully shielded from electromagnetic fields. For example, the sagging of the gas of free electrons in metallic shielding induces an electric field that can counterbalance the effect of gravity. Indeed, measurements based on dropping electrons led to a value of the acceleration of gravity, g, consistent with zero (instead of $g = 9.8\ \mathrm{m/s^2}$). A free-fall experiment with positrons has not yet been performed, owing to the lack of suitable sources of slow positrons. In the 1980s, a team proposed a free-fall measurement of g with antiprotons at CERN's Low Energy Antiproton Ring (LEAR), but it could not be performed before the closure of LEAR in 1996.

Using neutral antimatter such as antihydrogen can alleviate the disturbance from electromagnetic fields. The ALPHA collaboration at CERN's Antiproton Decelerator (AD) has set the first free-fall limit on g with a few hundred antihydrogen atoms held for more than 400 ms in an octupolar magnetic field. The results exclude a ratio of antimatter to matter acceleration larger than 110 (normal gravity) and smaller than –65 (antigravity). Plans to measure this ratio at the level of 1% by using a vertical trap are under way (*CERN Courier* June 2013 p5).

Positronium matters

The AEgIS collaboration at the AD uses positronium produced by bombarding a nanoporous material with a positron pulse derived from a radioactive sodium source. Positronium (Ps) is then brought to highly excited states with lasers and mixed with captured antiprotons to produce antihydrogen ($\bar{\mathrm{H}}$) through the reaction $\mathrm{Ps} + \bar{p} \rightarrow e^- + \bar{\mathrm{H}}$. The highly excited antihydrogen atoms possess large electric dipole moments and can be accelerated with inhomogeneous electric fields to form an antihydrogen beam. The sagging of the beam over a distance of typically 1 m is measured with a two-grating deflectometer by observing the intensity pattern with high-resolution (around 1 μm) nuclear emulsions. AEgIS is currently setting up, with antiprotons (around 10^5) and positrons (3×10^7) successfully stacked. A first measurement of g is planned in 2015 and the initial goal is to reach 1% uncertainty.

As a neutral system, positronium is also suitable for gravity measurements, but free-fall experiments are not easy because positronium lives for 140 ns only. Such studies require sufficiently cold positronium in long-lived, highly excited states and the appropriate atom optics. Preparations for a free-fall experiment at University College London are under way. ▷

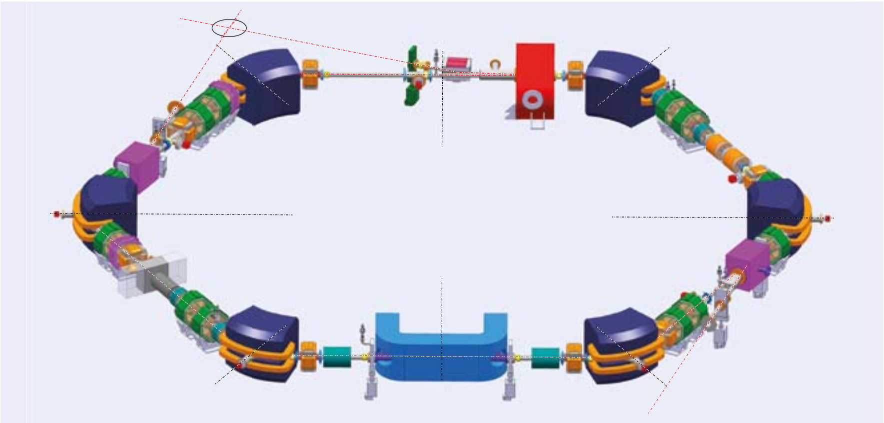


Fig. 1. Schematic of the ELENA 100 keV antiproton ring to be installed in the AD hall at CERN. (Image credit: ELENA team.)

At ETH Zurich, a team is measuring the 1s → 2s atomic transition in positronium with a precision better than one part per billion (1 ppb) by using a high-intensity positron beam that traverses a solid neon moderator and impinges on a porous silica target. The positronium ejected from the target is laser-excited to the 2s state and the γ-decay rate is measured by scintillating crystals, as a function of laser frequency. The 1s → 2s frequency can be calculated from hydrogen data. For hydrogen, the frequency is redshifted in the gravitational potential of the Sun, but the shift cannot be observed because the clocks used to measure the frequency are equally redshifted. However, for positronium (equal amounts of matter and antimatter) and assuming antigravity, measurements should yield a higher frequency than is calculated from hydrogen. At the level of 0.1 ppb, such studies could even test the hypothesis of antigravity as the Earth revolves around the Sun.

A similar experiment with muonium – an electron orbiting a positive muon – is planned at PSI in Switzerland. Ultra-slow muon beams with sub-millimetre sizes and sub-electronvolt energy for re-acceleration could also be used in a free-fall experiment employing gratings (a Mach–Zehnder interferometer).

Free-fall experiments

At CERN, the AD delivers bunches of 5.3 MeV antiprotons (3×10^7) every 100 s. However, storing antiprotons requires lower energies, which are reachable by inserting thin foils, albeit at the expense of substantial losses and degradation in beam size. Prospects for improved experiments are now bright with ELENA, a 30 m circumference electron-cooled ring that decelerates the AD beam further to 100 keV (figure 1). ELENA will be installed in 2015 and will be available for physics in summer 2017 (*CERN Courier* September 2011 p9).

The first free-fall experiment to profit from this new facility will be GBAR. Antihydrogen atoms will be obtained by the interaction of antiprotons from ELENA with a positronium cloud. The positrons will be produced by a 4.3 MeV electron linac. In contrast to AEgIS, the antihydrogen atom will capture a further positron to become a positively charged ion, which can be transferred to an electromagnetic trap, cooled to 10 mK with cold beryllium ions and then transported to a launching trap where the additional positron will be photodetached. The mean velocity of the antihydrogen atoms will be around 1 m/s and the fall distance will be about 30 cm. GBAR will be commissioned in 2017 with the initial goal of reaching 1% accuracy on *g*.

The sensitivity of GBAR, limited by the velocity distribution of the antihydrogen atoms, could be improved substantially by using quantum reflection, a fascinating effect that was discussed at the workshop. Antihydrogen atoms dropped towards a surface experience a repulsive force, which leads to gravitational quantum states. A similar phenomenon was observed with cold neutrons at the Institut Laue–Langevin (ILL) in Grenoble. Now, the ILL team proposes to bounce the atoms in GBAR between two layers – a smooth lower surface to reflect slow enough antihydrogen atoms and a rough upper surface to annihilate the fast ones. Transition frequencies between the gravitational levels – which depend on *g* – could also be measured by recording the annihilation rate on the bottom surface. Provided that the lifetime of these antihydrogen levels is long enough, orders of magnitude improvements could be obtained on the determination of *g*.

Atom interferometers might be able to measure *g* to within 10^{-6}. In a Ramsey–Bordé interferometer, the falling atom interacts with pulses from two counter-propagating vertical laser beams. Having absorbed a photon from the first beam, the atom is stimulated to emit another photon with the frequency of the second beam, thereby modifying its momentum. The signal from the annihilating antihydrogen atom, for example at the top of the interferometer, interferes with the one from another atom that has equal momentum but was not subject to the laser kick. The interference pattern will depend on the value of *g*.

In the more distant future, the Facility for Low-energy Antiproton and Ion Research (FLAIR) will become operational at GSI. As an extension to the high-energy antiproton facility, FLAIR will consist of a low-energy storage ring decelerating antiprotons from 30 MeV to 300 keV, followed by an electrostatic ring capable of reducing the energy even further, down to 20 keV. At FLAIR the antiproton flux will be an order of magnitude higher than at ELENA, and slow extracted antiproton beams will be available for experiments in nuclear and particle physics.

The question of how large an effect these free-fall experiments could measure cannot be answered without theoretical assumptions, such as exact symmetry between matter and antimatter (the CPT theorem). However, string theory can break CPT. The standard model extension proposed by the Indiana/Carleton group involves Lorentz and CPT violation (*CERN Courier* November 2013 p31). Also, atoms and nuclei contain virtual antiparticles in amounts that depend on the atomic number. The calculable quantum corrections agree with measurements, arguing against antigravity. However, there is a huge discrepancy in the value of the cosmological constant estimated from vacuum particle–antiparticle pair fluctuations, which might question our understanding of the interaction between gravity and virtual particles. As pointed out at the workshop, if all of the theoretical assumptions are valid, then antimatter experiments should not expect to see discrepancies in *g* at a level larger than 10^{-7}. Ultimately, the issue must be settled by experiments.

To compare with matter, a presentation was given on the 10^{-9} precision achievable on *g* at the Swiss Federal Institute of Metrology (METAS) using a free-fall interferometer. Together with improved measurements of Planck's constant with a watt balance, this might lead to a re-definition of the kilogram based on natural units.

The workshop also included a session on antimatter in the universe. Is there any antimatter and could it repel matter (the Dirac–Milne universe) and provide the accelerating expansion? Can the excess of positrons observed above 10 GeV by balloon experiments, the PAMELA satellite experiment and, more recently, the Fermi Gamma-ray Space Telescope and the Alpha Magnetic Spectrometer (AMS-02), be explained by antimatter annihilation?

In his summary talk, Mike Charlton of Swansea University concluded that "the challenge of measuring gravity on antihydrogen remains formidable", but that "in the past decade the prospects have advanced from the totally visionary to the merely very difficult".

The workshop, with 28 plenary talks, was attended by 70 participants. A visit to the house where Einstein spent the years 1903–1905 and dinner at Altes Tramdepot were part of the social programme.

● Further reading

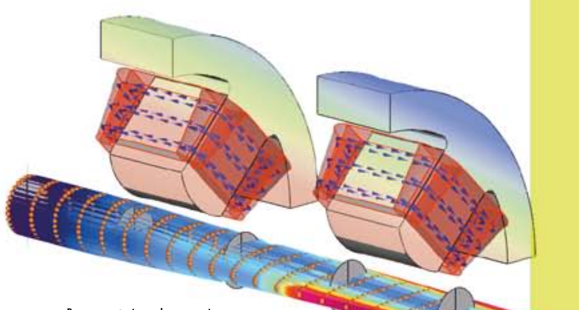
For more details, visit www.einstein.unibe.ch/workshops/wag2013.html. Proceedings will be published by the *International Journal of Modern Physics*.

Résumé

Antigravité à WAG 2013

L'antimatière se comporte-t-elle de la même façon que la matière sous l'influence de la gravité, ou bien au contraire de façon opposée ? Le 2e atelier international sur l'antimatière et la gravitation a rassemblé des spécialistes à Berne en novembre pour examiner les aspects expérimentaux et théoriques de ces questions. L'une des clés du problème réside dans les expériences de chute libre permettant de mesurer l'accélération de la gravité, g. Ces expériences sont extrêmement difficiles à réaliser sur des particules chargées, mais de premières mesures ont été effectuées récemment sur de l'antihydrogène neutre, et il est prévu de réaliser des expériences spécifiques sur l'antihydrogène, le positonium et le muonium.

Claude Amsler, chair of WAG 2013, Albert Einstein Center for Fundamental Physics, University of Bern.



Faces & Places

AWARDS

Prize time in the US, Japan and Europe

In December, the Fundamental Physics Prize Foundation announced the awarding of the 2014 Fundamental Physics Prize to Michael Green of the University of Cambridge, and John Schwarz of the California Institute of Technology, for opening new perspectives on quantum gravity and the unification of forces. Schwarz and Green were honored for developing superstring theory during their collaboration between 1979 and 1986. Its predecessor, string theory, originated in the late 1960s in response to the discovery of many new particles via accelerator experiments.

The prize, which recognizes transformative advances in the field, is awarded by the Fundamental Physics Prize Foundation, which was established in July 2012 by Yuri Milner to recognize groundbreaking work in the field.

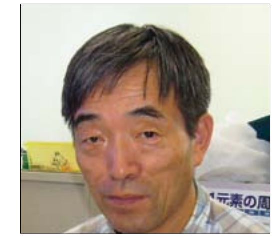
In Japan, Takahito Kondo, Tomio Kobayashi and Shoji Asai have been awarded the 2013 Nishina Memorial Prize for their contribution to the discovery of the Higgs boson. Kondo of KEK, Kobayashi of the International Center for Elementary Particle Physics at the University of Tokyo, and Asai of the University of Tokyo, are all members of the ATLAS collaboration.

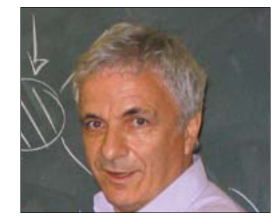
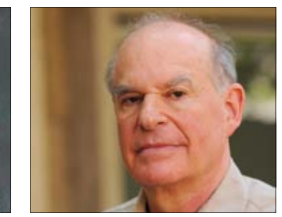
They share the prize with Hidetoshi Katori of the RIKEN research institute and the University of Tokyo, honoured for the invention of optical-lattice clocks, and Yoshiro Takahashi of Kyoto University, cited for the creation of ultracold quantum systems of ytterbium atoms.

The Nishina prize is awarded annually by the Nishina Memorial Foundation to young physicists for their achievements in the field of atomic and subatomic physics. The foundation was established in 1955 to commemorate Yoshi Nishina, who originated the study of nuclear physics in Japan.

Another Japanese physicist has been honoured in Europe with the Julius Wess Award 2013 for outstanding achievements in elementary particle and astroparticle physics. Takaaki Kajita of the Institute for Cosmic Ray Research at the University of Tokyo has been recognized for his outstanding contributions to neutrino physics, and especially for his discovery of neutrino oscillations at the Super-Kamiokande detector. Kajita has studied neutrinos at the Kamiokande experiment and subsequently at Super-Kamiokande for more than 25 years. In 1988 he and his colleagues observed a deficit in atmospheric muon-neutrinos, which could be later explained by the occurrence of neutrino oscillations.

The Julius Wess Award is dedicated to the memory of Julius Wess, who worked for 20 years at the Karlsruhe Institute of Technology (KIT). Kajita received the award at a ceremony at the KIT Center for Elementary Particle and Astroparticle Physics in December.




Top, left to right: Takahito Kondo, Tomio Kobayashi and Shoji Asai. (Image credits: KEK, ICEPP and UTokyo.)

Middle: Michael Green, left, and John Schwarz. (Image credits: DAMPT and Caltech.)

Bottom: Presentation of the Julius Wess Award to Takaaki Kajita, centre, with his wife and Johannes Blümer, vice-president at KIT, far right, Detlef Löhe, second right, and Ulrich Nierste, far left. (Image credit: KIT.)

Left to right: Nobel laureates Samuel Ting (Massachusetts Institute of Technology), George Smoot (University of California, Berkeley, Paris Diderot University) and Frank Wilczek (Massachusetts Institute of Technology), who received honorary doctorates from Gustavus Adolphus College in Saint Peter, Minnesota, on 1 October. They were speaking at the college's 49th annual Nobel conference on "The universe at its limits". Other presenters at the conference were George Coyne (Le Moyne College, Syracuse), Alexei Filippenko (University of California, Berkeley), S James Gates Jr (University of Maryland), Lawrence Krauss (Arizona State University), and Tara Shears (University of Liverpool). Videos of the conference and other information can be found at https://gustavus.edu/events/nobelconference/2013/. (Image credit: Terry Clark.)

Collaboration

Indonesia and Bangladesh strengthen ties with CERN

At a ceremony held in Jakarta on 21 October, the Indonesian Institute of Sciences (LIPI) signed a memorandum of understanding with the ALICE collaboration, marking the first official collaboration between an Indonesian institute and an experiment at CERN. Paolo Giubellino, the ALICE spokesperson, and Emmanuel Tsesmelis, CERN's deputy head of international relations, attended the signing ceremony, at which LIPI was represented by Lukman Hakim, the institute's chair, and Laksana Tri Handoko, the LIPI team leader.

With the agreement, LIPI will contribute initially at ALICE in the area of grid computing. The team there has installed two clusters, in Bandung and Cibinong, which have been connected to the ALICE Grid. There is also keen interest in the ALICE O^2 upgrade project. In addition, the high-energy physics group that is being created at LIPI is expected to contribute to the ALICE physics programme and to the upgrade of the experiment. The agreement exemplifies LIPI's effort to be more active and gain international recognition as a research centre of excellence.

Bangladesh took the first steps in collaborating with CERN on 14 November, when education secretary Kamal Abdul Naser Chowdhury visited the laboratory to sign an expression of interest, together with CERN's director-general, Rolf Heuer. The implementation of the expression of interest could pave the way for an international co-operation agreement that would further formalize and broaden the collaboration between CERN and the Bangladeshi high-energy physics community.

The current agreement will help scientists, engineers and students from Bangladesh to gain valuable experience in both experimental and theoretical particle physics, as well as in aspects of particle accelerators, particle detectors and information technology. In this way, it will facilitate the professional development and research skills of scientists, engineers and students from research organizations and universities across the country, and could lead to new scientific practices for nuclear scientists, research organizations and university students.

(Top) At the signing ceremony in Jakarta in November, with Lukman Hakim, chair of LIPI (front row, centre), Laksana Tri Handoko, LIPI team leader (back row, centre), Emmanuel Tsesmelis, CERN (front, second from right), and Paolo Giubellino, ALICE spokesperson (front right). (Image credit: LIPI.)

(Below) Kamal Abdul Naser Chowdhury, education secretary for Bangladesh, left, and CERN's director-general, Rolf Heuer, shake hands after signing an expression of interest between Bangladesh and CERN.

At a ceremony held on 15 January at CERN, the Israeli flag was hoisted for the first time to join the other 20 flags of the organization's member states, after UNESCO officially recorded Israel's accession as a new CERN member state. This followed the resolution unanimously adopted by CERN Council on 12 December (CERN Courier January/February p5). After the ceremony, Avigdor Liberman, deputy prime minister and minister of foreign affairs of the state of Israel, visited the LHC tunnel and the ATLAS experiment, accompanied by a delegation of officials and representatives of the Israeli scientific community.

Anniversary

CALTECH celebrates 50th anniversary of quark prediction

In December 1963, Murray Gell-Mann mailed a manuscript of a paper in which he proposed the quark model of hadrons. It arrived in the editorial office of *Physics Letters B* on 4 January and was published on 1 February 1964 with the title "A schematic model of baryons and mesons". On the 50th anniversary of the prediction of quarks, the California Institute of Technology (Caltech) held a symposium on 9–10 December 2013 to celebrate Gell-Mann's scientific legacy.

After opening remarks by Tom Soifer, chair of the Division of Physics, Mathematics, and Astronomy at Caltech, there were talks by Maria Spiropulu ("Higgs: from Discovery to Beyond"), James Hartle ("The State of the Universe"), Harald Fritzsch ("Murray Gell-Mann"), David Politzer ("The $\Delta I = 1/2$ Rule"), Pierre Ramond ("The Flavor Ring"), Barry Barish ("Quarks: An Experimentalist's Perspective"), Barton Zwiebach ("Generalized Geometry for String Theory"), John Schwarz ("Murray Gell-Mann and String Theory"), and Geoffrey West ("The Renormalization Group and Scaling from Quarks to Jaguars").

The symposium concluded with remarks by Gell-Mann in which he described his view on the significance of the quark prediction. There were lively discussions during intermissions and lunches. The banquet was held at the Caltech President's House, hosted by Edward Stolper, the interim president and the provost. Among those attending the banquet was Marvin Goldberger, Caltech's 5th president and Gell-Mann's long-time friend and collaborator.

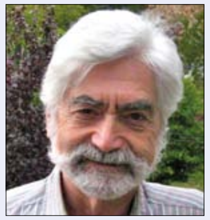
Quarks were also proposed by George Zweig, which he called "aces." After receiving his PhD from Caltech in 1963, Zweig spent 1963–1964 at CERN, where he wrote a paper entitled "An SU_3 Model for Strong Interaction Symmetry and Its Breaking" (dated 17 January 1964) and a sequel (dated 21 February 1964). However, CERN required that papers written by junior members of the theory group be approved before they could be submitted for publication. Moreover, Zweig planned to publish in *Physical Review*, but CERN required that papers had to be published in European journals. Therefore approval was not forthcoming for these papers, so it took a while for his work to be fully appreciated. In 1964, Zweig returned to Caltech, where he was a professor in the high-energy theory group for 20 years. Unfortunately, Zweig was unable to attend the symposium.

The symposium took place on the same days as the Nobel Prize ceremony in Stockholm, where François Englert and Peter Higgs were honored for their theoretical discovery of the electroweak symmetry-breaking mechanism. It was a wonderful week for celebrating the completion of the Standard Model of particle physics.

● For more details, see http://hep.caltech.edu/gm/.

● *John Schwarz and Hirosi Ooguri, Caltech.*

Gell-Mann during after-dinner speeches at the celebratory banquet. (Image credit: Caltech.)



Last September, George Zweig visited CERN to give a colloquium entitled "Concrete Quarks; the Beginning of the End". In his talk, Zweig discussed the steps that led him to introduce his "aces" model while he was working in CERN's Theory Division back in 1964, and also reviewed some of the main developments since that time. Following his work in the field of high-energy particle physics, Zweig moved to a totally different field, neurobiology, first doing experiments to understand how sound is represented in the auditory cortex of the cat and then moving on to the problem of characterizing cochlear mechanics. (Image credit: G Zweig.)

● *For a video of the colloquium, see http://cds.cern.ch/record/1602433. For an interview with Zweig, see http://ph-news.web.cern.ch/content/interview-george-zweig.*

CONFERENCE

IPAC 2014 to take place in Dresden

This year, it is again the turn of Europe to host the International Particle Accelerator Conference (IPAC), which since 2010 has combined the former continental conferences (*CERN Courier* November 2009 p42). Starting in Kyoto, it has been held consecutively in Asia, Europe and North America, going to Shanghai to start the cycle again in 2013. IPAC'14 will take place at the International Congress Center Dresden on 15–20 June, hosted by the Helmholtz-Zentrum Dresden-Rossendorf and supported by the GSI Helmholtzzentrum für Schwerionenforschung, Helmholtz-Zentrum Berlin and DESY.

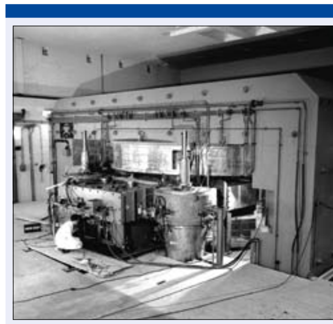
The conference programme consists of varied talks focusing on R&D, planning and prospects for future developments in the field of particle accelerators. One highlight will be a session dedicated to the presentation of the 2014 European Accelerator Prizes, awarded by the European Physical Society Accelerator Group. The scientific programme will be composed of invited oral presentations, contributed oral presentations and poster sessions. There will be a student poster session during delegate registration on the Sunday afternoon. An industry exhibition will also be held in the congress centre, allowing conference participants to find out more about products and services from companies that are active in the field of accelerators and relevant areas of education.

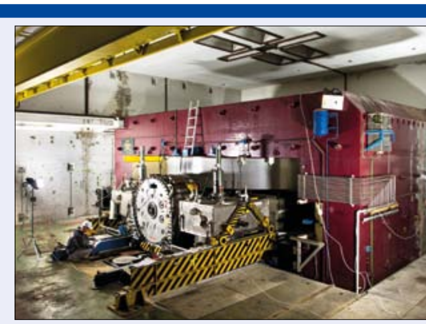
● For further information, visit http://www.ipac14.org/.

VISITS

On 12 January, Hungarian prime minister **Viktor Orbán**, second from right, toured the LHC with **József Pálinkás**, president of the Hungarian Academy of Sciences, left, **Marta Bajko**, of CERN's Technology Department, and the director-general, **Rolf Heuer**, right. The visitors went on to see the CMS experimental area and the CERN Computing centre.

The Japanese senior vice-minister of education, sports, culture, science and technology, **Yoshita Sakurada**, centre, came to CERN on 17 January. During his visit he saw the LHC tunnel, accompanied by, to the left (with blue tie), **José Miguel Jiménez**, head of the Technology Department, and to the right, **Lyn Evans**, Linear Collider Collaboration director.





The 600 MeV Synchrocyclotron (SC) was CERN's first accelerator. Built as a stop-gap and training machine until the more powerful Proton Synchrotron (PS) started, it provided beams for CERN's first experiments in particle and nuclear physics. In the view taken in October 1957, left, Joop Vermeulen is seen kneeling near the tuning fork RF tank in front of the large magnet coils, less than three months after the SC had accelerated its first protons. Vermeulen was one of the early pioneers at CERN involved in the construction of the SC. The SC became a remarkably long-lived machine. In 1964, it began to be used for nuclear physics alone, leaving particle physics to the PS, which had started up in 1959. Then in 1967, it started to supply beams for ISOLDE, CERN's on-line isotope separator, which produces beams for research ranging from pure nuclear physics to astrophysics and medical physics. In 1990, ISOLDE was transferred to the PS Booster and the SC closed down after 33 years of service.

The big magnet remained in Building 300, however, while the rest of the 300 m² building was used as a storage room after the accelerator shut down. Soon, a public exhibition will breathe new life into the hall. Cleaning the SC hall – seen on the right in December 2012 – took about seven months and involved an external company as well as many CERN services, from the transport group and the magnet group to the civil-engineering team.

OBITUARIES

Franco Selleri (1936–2013)

Franco Selleri died in the city of Bari, Italy, on 21 November, from a stroke following a long disease. A leading theoretical physicist, he made original and important contributions to particle physics and on the foundations of quantum mechanics, relativity and epistemology.

Born in Bologna, Franco studied at the Alma Mater Studiorum, where he became Dottore in Fisica cum laude with his thesis on "Analisi dell'interazione pione nucleone", under the supervision of Gianpietro Puppi. Puppi and other members of his group were analysing bubble-chamber film from Columbia University, focusing on pion–nucleon cross-sections in the 500 MeV–1 GeV energy region. Franco calculated the spectra at an incident pion kinetic energy of 960 MeV. He was 22 years old.

He soon became well known because he formulated, with Francesco Bonsignori, the "peripheral model". The model assumed that the only important contribution to the interaction between the incoming particle and the target nucleon that was responsible for single-pion production came from diagrams with only one virtual intermediate pion. This model was extended to proton–proton interactions during Franco's stay at CERN (1959–1961), thanks to the contribution of Ezio Ferrari and the suggestions of Sergio Fubini. The peripheral model, confirmed by the S-matrix theory of strong interactions of Geoffrey Chew, also received significant experimental support, and can be considered the progenitor of the Drell–Yan process in that it concerns the exchange of a virtual particle in strong interactions.

Following a period of research at Saclay and Cornell, Franco was called to teach and lead research at the Physics Department of the University of Bari, where from 1980 he served as full professor of theoretical physics.

In the late 1960s, dissatisfied by the ongoing developments in particle physics and thanks to a book by Bernard d'Espagnat on quantum mechanics, Franco passed many months at the University of Nebraska reading as much as possible about the foundations of the subject. He submitted a paper in 1976 to the *Annales de la Fondation Louis de Broglie* on "Quantum Mechanics and Reality". De Broglie wrote the following in a letter addressed to Franco the same year, commenting on the paper: *"...Plus tard,*

France Selleri. (Image credit: Foundations of Physics *34 1612.)*

après le triomphe des idées de Niels Bohr et de l'Ecole de Copenhagen, je me suis rallié sans enthusiasme à leur opinion et je les ai introduit, non sans quelques réticences dans mon enseignement. Mais, après depuis près de 2 ans, j'ai cherché à retablir en physique théorique mon idée primitive d'une causalité rigoreuse...".

Following a philosophical point of view, Franco did not want to give up on the principle of causality, and supported wave-particle duality and the existence of hidden variables in the microscopic world. Because of this he came into contact with John Bell who, in a paper on the Einstein–Podolsky–Rosen paradox, formulated his theorem that provided the possibility of verifying experimentally the validity of quantum mechanics. In another paper, in *Nuovo Cimento*, Franco formulated a stronger form of Bell's inequality, which is still not disproved by any experiment. As a strong defender of locality in quantum mechanics, Franco supported David Bohm's wave-pilot approach and the statistical formulation of quantum mechanics according to Landau and Lifshitz. His book *Die Debatte um Die Quantentheorie* has been translated into French, Greek, Italian, Japanese and Polish.

Franco's belief in wave-particle duality pushed him to find a means through which the wave could propagate, so he focused his attention on relativity, where the synchronization of clocks between observers plays an important role. Hans Reinchebach has demonstrated that it is possible to formulate many theories equivalent to special relativity through the variation of a parameter epsilon between 0 and 1. On the basis of six experimental proofs, Franco fixed epsilon to zero, which gave him the possibility to return to a neo-Lorentzian approach based on the existence of a privileged reference system (the cosmic microwave background, for instance). Doing so, he replaced the Lorentz transformations with a new set that he called "inertial transformations". In this way, the Sagnac effect, the twin paradox and the trip from the future to the past – explained by mainstream research with some intellectual contorsions – find an easy and elegant explanation. Franco called his theory weak relativity.

From the epistemological point of view, Franco was in favour of a reality existing independently of human observation. He was in close contact with Karl Popper who, though very old, expressed his esteem for Franco's work on the subject by taking part in a conference on the subject that Franco organized in 1985 in Bari.

Franco was an excellent, clear lecturer. His courses and speeches were popular among students and the general public because he believed that everybody should have the possibility to understand physics. About 50 students graduated under him, many of whom are now full professors in various universities. He authored 350 papers and many books, the one on quantum mechanics being the best known worldwide. A fluent speaker of English, French and German, he had broad interests, from astronomy to medical physics, art and politcs.

Franco was director of the INFN section of Bari and was on the editorial board of several international publications. He was awarded many honours and was a member of the Italian Physics Society, the American Physical Society, the New York Academy and the Foundation Louis de Broglie, among others.

A hard worker with a strong personality, Franco believed that theoretical physics cannot be driven by mutual consensus but only by experimental proofs. He will be greatly missed for his passion for physics, his intellectual honesty and his solidarity with the working class. To his family, we offer our deep condolences.

● *Michele Barone, on behalf of friends, collaborators and colleagues everywhere.*

Erik Uggerhøj (1931–2014)

It might not have been obvious that Erik Uggerhøj would eventually be a professor in physics at Aarhus University, but via a roundabout route – including carpentry and school teaching – this was what he achieved, becoming an inspirational figure in the university.

Erik was a true entrepreneur in experimental physics. His flair for recognizing the numerous possibilities of a new machine gave birth to many instruments, including the particle accelerators in the Department of Physics at Aarhus in the 1960s. In the 1970s, he became engaged in using electrons and positrons, and at CERN new possibilities based on the duality of charged particles appeared. The use of these particles at high velocities, up to close to the speed of light, opened up new research opportunities in an otherwise classical field – the passage of charged particles through matter – which Jens Lindhard had initiated at Aarhus University in the 1960s.

While working at the accelerators at CERN, especially the synchrotrons and storage rings, Erik realized the possibilities that lay in building similar facilities at Aarhus for areas of physics – in particular, atomic physics – that interested many of the researchers there. He managed to gain the support of a large number of physicists for a new accelerator – the Aarhus Storage Ring for Ions and Electrons, Denmark (ASTRID) – which could be used for a number of atomic-physics experiments. Very early on, Erik saw the potential of using ASTRID not only to store ions as originally foreseen, but for storing high-energy electrons for the production of high-intensity short-wavelength synchrotron radiation, i.e. soft X-rays. The accelerator was so big – for a university site – that a new underground laboratory had to be built below the car park between the chemistry and physics departments. The physics department at Aarhus University remains pretty much the only one worldwide that has a synchrotron in its basement.

Erik Uggerhøj. (Image credit: Niels Hertel, Aarhus University.)

In the late 1990s, Erik realized that an area of significant potential interest for ASTRID, – that of hard X-rays – could not be reached with the accelerator's relatively low energy. Having previously used X-rays at DESY, he enthusiastically proposed a synchrotron-radiation facility for hard X-rays. A new experiment hall was built, including lab space, with government funding in 1997. The construction was finished and in use for many years before finance for a new ring for high-brilliance soft X-rays – ASTRID2 – was granted in December 2008. It is a tribute to Erik's foresight that the hall to house ASTRID2 was available when it was needed.

Another specialty of Erik's was slow antiprotons. At the beginning of the 1980s, there was growing interest in understanding the complex mechanisms generated by collisions between simple charged particles and atoms. At what had become the Department of Physics and Astronomy, many researchers had worked on these themes thanks to the local access to both proton and electron accelerators. However, it was Erik who created a breakthrough in this research by suggesting comparing proton and antiproton collisions, which CERN was able to provide from the 1980s. This work has also contributed to the national centre for particle therapy for the treatment of cancer at Aarhus University Hospital in Skejby, which is currently under construction.

Erik was a notable personality at CERN, where he performed his first experiments in the mid-1970s with Georges Charpak, and throughout the years he advocated numerous experiments. This involved extensive travelling and he was employed at CERN several times, moving his family there. Erik thrived both when talking informally with the management in the CERN canteen and when taking the lead with the drilling machine in laying the groundwork for the next experiment. He had great ingenuity and enjoyed the challenges his ideas fostered, following them through until they crystallized into experiments that could be performed. He had incredible enthusiasm and persuasiveness, and would present his case with conviction and passion. In this way, Erik almost always achieved his goal.

He also had a great "team spirit". Almost no one came to CERN without being invited on an outing where Erik was happy to let the younger generation go wandering in the mountains while he concentrated on the perfect barbecue for later dining under the sky.

That Erik has left so many significant footprints within natural sciences, and especially in physics, is also a result of his ability to engage and convince other people, irrespective of their age and rank – from directors, rectors and deans to co-workers, technicians and skilled workmen. He was a splendid personality who left his mark.

● *Søren Pape Møller, David Field, Helge Knudsen and Ulrik Uggerhøj, Aarhus University.*

Letters

Pontecorvo and neutrino physics

In connection with the centenary of Bruno Pontecorvo's birth, *CERN Courier* (September 2013 p78) published an article "Pontecorvo and neutrino physics" by Vadim Bednyakov, a collaborator of Pontecorvo's in his later years.

Pontecorvo, given his remarkable imagination, concentration and insight, made several important contributions to progress in particle physics in the 20th century. However, in his later years, he also imagined some contributions that he did not make, and this involves, to some extent, some of my own work. In addition, the article largely credits Pontecorvo with the foundation of our understanding of neutrino oscillations. I have tried to understand this history and will make some comments. Much credit is given to Pontecorvo for the theoretical prognosis of neutrino oscillations, but as best I can determine, Pontecorvo's contributions here are much less clear than generally suggested (Pontecorvo 1957, 1959, 1967). I believe that these questions are of interest for understanding the history of the physics involving neutrinos, so as to justify this review.

Universality of the Fermi interaction. I came to know Pontecorvo in 1947 and 1948, at the time when he was a physicist at the nuclear reactor at Chalk River, Canada, and when he came, I think twice, to Chicago to see Fermi, who had been his teacher in Rome and who was then my thesis adviser. One or two years later, Pontecorvo emigrated to the Soviet Union. At the time of his visits, he was involved at Chalk River with E P Hincks, perhaps part time, in a cosmic-ray experiment on stopped "mesotrons" (now known as muons) using Geiger counters. This had similarities to my thesis experiment, which showed that the energy spectrum of the electrons in mesotron decay is continuous (Steinberger 1949). This turned out to be a much more interesting result than Fermi and I realized. Immediately three papers, one by T D Lee, M Rosenbluth and C N Yang, another by J Tiomno and J A Wheeler, and the third by G Puppi, pointed out that this showed that, in addition to the Fermi nucleon and electron-neutrino currents, there was a third current, a muon-neutrino current, of equal amplitude. At the time this was called the "Puppi triangle". It demonstrated the universality of the Fermi interaction. The Hincks–Pontecorvo experiments were much smaller and the geometries quite different (Hincks and Pontecorvo 1947, 1948, 1950). Their results did not permit conclusions about the continuity of the decay-electron spectrum, and at the time no such claim was made. Nevertheless, in his later years, Pontecorvo claimed that these experiments permitted the conclusion that the muon-decay spectrum is continuous, as repeated in the *CERN Courier* article.

It is interesting to recall that Pontecorvo had anticipated the universality of the Fermi interaction already in 1947, in a very different way. Following the publication in 1946 by Conversi, Pancini and Piccioni of the experiment that showed that the nuclear interaction of the mesotron is too weak for it to be the particle proposed by Yukawa as responsible for nuclear forces, in a letter to *Physical Review* Pontecorvo noted that the result of that experiment – namely that negative mesons stopped in carbon absorbers decayed normally, whereas those stopped in iron absorbers are captured by the nucleus before their decay, within the uncertainty factor $(Z_{Fe}/Z_C)^2$, that is, about 20 – showed that the nuclear interaction amplitude of the mesotron is the same as that of the Fermi interaction in β decay, and that therefore there might be a universal Fermi interaction (Pontecorvo 1947). This, now clearly correct, idea was universally rejected by the physics community at the time. The notion of a parallel between the electron, the particle in atoms, and the mesotron of cosmic rays was just too imaginative. Fermi clearly rejected it. A year later, after my thesis experiment, the universality of the Fermi interaction was accepted by everyone, but Pontecorvo's 1947 letter is not remembered. It might be of interest to note that probably Pontecorvo himself was not convinced of the correctness of the idea, or he would have proposed the obvious way to test it – that is by measuring the capture rates in elements with atomic number between those of carbon and iron.

Two neutrinos. I am personally indebted to Pontecorvo for proposing, in 1959, to check experimentally if the neutrinos associated with muons in pion and kaon decay are the same, or not, as those in β decay, and that the higher energy accelerators, then under construction at Brookhaven and CERN, would permit neutrino beams of energy high enough to allow such an experiment (Pontecorvo 1959) – the experiment for which M Schwartz, L Lederman and I later shared the Nobel prize (Danby *et al.* 1962). Independently, Schwartz had proposed that neutrino beams would permit the study of weak interactions at higher energy, but he did not consider the particular question of the possible inequality of the two neutrinos, proposed by Pontecorvo (Schwartz 1960).

Pontecorvo and neutrino oscillations. Pontecorvo's work on what he called neutrino "oscillations" dates back to the 1950s and 1960s, but the processes that he then referred to as oscillations, such as neutrinos changing to (μ^+e^-), or (μ^-e^+), or $\nu^\mu \rightarrow \nu^e$, or $\nu \rightarrow \bar{\nu}$ cannot be related to neutrino oscillations as we now observe and understand them (Pontecorvo 1957a, 1957b, 1967, Gribov and Pontecorvo 1969). Neutrino oscillations were discovered, serendipitously, by M Koshiba and collaborators, in the 1990s, in the Kamiokande and later Super-Kamiokande detectors, which had been built to look for proton decay (Nakahata *et al.* 1986, Hirata *et al.* 1988, Fukuda *et al.* 1994, Fukuda *et al.* 1998). The 1969 paper by Gribov and Pontecorvo is, to my knowledge, the first work that imagined mass–flavour mixing, which, as we now know, is the mechanism of neutrino oscillations. At the time (1969), it was an imaginative, mathematical invention, without observational motivation, and was ignored. The actual neutrino oscillation mechanism, that is, the mass–flavour eigenstate mixing, was understood in the mid-1980s, with the important help of the work of Eliezer and Ross (Eliezer and Ross 1974).

● *Jack Steinberger, CERN.*

● Further reading

G Danby *et al.* 1962 *Phys. Rev. Lett.* **9** 36.
S Eliezer and D A Ross 1974 *Phys. Rev.* D **10** 3088.
Y Fukuda *et al.* 1994 *Phys. Lett.* B **335** 237.
Y Fukuda *et al.* 1998 *Phys. Rev. Lett.* **81** 1562.
V Gribov and B Pontecorvo 1969 *Phys. Lett.* **28B** 493.
E P Hincks and B Pontecorvo 1947 *Phys. Rev.* **73** 258.
E P Hincks and B Pontecorvo 1948 *Phys. Rev.* **74** 697.
E P Hincks and B Pontecorvo 1950 *Phys. Rev.* **77** 102.
K S Hirata et al. 1988 *Phys. Lett.* B **205** 416.
M Nakahata et al. 1986 *J. Phys. Soc. Japan* **55** 3786.
B Pontecorvo 1947 *Phys. Rev.* **72** 246.
B Pontecorvo 1957a Z*h. Eksp. Teor. Fiz.* **33** 549.
B Pontecorvo 1957b *Zh. Eksp. Teor. Fiz.* **34** 247.
B Pontecorvo 1959 *Zh. Eksp. Teor. Fiz.* **37** 1751; translation: 1960 *Sov. Phys. JETP* **10** 1236.
B Pontecorvo 1967 *Zh. Eksp. Teor. Fiz.* **53** 1717.
M Schwartz 1960 *Phys. Rev. Lett.* **4** 396.
J Steinberger 1949 *Phys. Rev.* **75** 1136.

Neutrinoless double beta decay

In the November 2013 issue of *CERN Courier*, p42, a letter by H V Klapdor-Kleingrothaus puts forward the question about progress in the field of neutrinoless beta decay (0νββ). In contrast to his doubts, the GERDA collaboration would like to answer this question positively.

There has been tremendous progress in the field since his own last measurement – much beyond "some fresh breeze" – first by the number of experiments investigating different isotopes and different methods, and second by experimental measures to improve the background compared to the precursor ^{76}Ge experiments, Heidelberg-Moscow (HdM) and IGEX. Moreover, it is surprising to see that the letter quotes conference contributions of GERDA only, but not our refereed articles.

The GERDA design follows the idea of Gerd Heusser (1995 *Ann. Rev. Nucl. Part. Sci.* **45** 543). This idea was tested with liquid nitrogen in the GENIUS test facility without success by Klapdor-Kleingrothaus (2008 *Int. J. Mod. Phys. E* **17** 505). The GERDA collaboration refurbished the same germanium crystals and achieved a stable operation in liquid argon over a programmed period of 1.5 years. With this technique, the background was reduced by about one order of magnitude with respect to the historical HdM and IGEX experiments.

The GERDA collaboration is well aware of the 2006 article by Klapdor-Kleingrothaus (*Mod. Phys. Lett.* **A21** 1547). The reasons why we do not compare to this result – as requested in his letter to *CERN Courier* – are mentioned in our publication on 0νββ results (2013 *Phys. Rev. Lett.* **111** 122503) and discussed by B Schwingenheuer (2013 *Ann. Physik* **525** 269). The statistical error on the signal counts given is too small, the

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significance of the peak is not estimated correctly and no efficiency correction is applied in the calculation of the half-life time. For this reason, GERDA compares its result to the claim published in 2004 (*Nucl. Instr. Methods* **A522** 371 and *Phys. Letts. B* **586** 198).

In the above-mentioned 2006 paper, the peak reconstructs 2 keV below the Q-value of the decay. Double escape-peak events in ^{208}Tl or ^{56}Co decays are proxies for the $0\nu\beta\beta$ signal and do not show such a shift in energy with respect to calibration lines at full energy. Therefore, the quoted ballistic deficit is not relevant in the energy reconstruction of the GERDA data and the signal line should appear at the Q-value.

The GERDA analysis followed a rigorous analysis path, where parameters for background and pulse shape have been fixed prior to the "unblinding" and are documented in papers (arXiv:1306.5084, accepted by *EPJC*, and 2013 *EPJC* **73** 2583, respectively) prior to the publication of the physics results (2013 *Phys. Rev. Lett.* **111** 122503). Owing to the reduced background, we reach a higher sensitivity than HdM after 21 kg yr exposure and exclude the claim of 2004 with 99% probability.

● *The GERDA collaboration.*

● All GERDA publications are available at www.mpi-hd.mpg.de/gerda/public/index.html.

New products

Aerotech's Npaq 6U is a high-power drive rack that uses plug-in amplifiers supporting both linear and pulse-width modulation (PWM) topologies to control brushless, DC brush or stepper motors. PWM amplifiers offer up to 320 VDC operating voltage and 30 A peak current capability. Linear amplifiers provide up to 80 V and 20 A peak current for high-power, low-noise applications. The Npaq 6U performs both current-loop and servo-loop closures digitally to ensure the highest level of positioning accuracy and rate stability. For further information, contact Steve McLane, tel +1 412 967 6854, e-mail smclane@aerotech.com or visit www.aerotech.com/product-catalog/drives-and-drive-racks/npaq-6u.aspx.

Diamond Systems has unveiled the Epsilon-12G2, a rugged, managed Layer 2+ Ethernet switch module that offers 12 10/100/1000 Mbps copper twisted pair ports and two small form-factor pluggable (SFP) sockets in a compact COM Express form factor. The dual SFP socket interfaces to 1 G fibre Ethernet networks. The standalone switch, which operates across a temperature range of –40 °C to +85 °C, does not require a host computer interface. A 480 MHz MIPS processor embedded directly into the switch manages all switch functions. For further information, tel +1 800 367 2104, e-mail sales@diamondsystems.com or visit www.diamondsystems.com/products/epsilon12g2.

Intersil Corporation has expanded its family of power-management controllers with a highly-integrated digital DC/DC power controller that reduces design risk, time and cost for developers of complex power systems. The ZL8800 is a dual-channel/dual-phase controller that uses a charge-mode control-loop technology to deliver fast transient response without the need for compensation, reducing design time. Intersil has also introduced the PowerNavigator graphical user interface (GUI), which lets users design digital power into their systems without writing code. Its drag-and-drop interface significantly shortens design time. The PowerNavigator tool is available as a free, downloadable GUI. For further information, contact Shannon Pleasant tel +1 512 382 8444, e-mail spleasant@intersil.com or visit www.intersil.com.

Spectrum has launched the digitizerNETBOX, which is aimed at engineers who need a high-precision, multi-channel measurement system. The digitizerNETBOX comes complete with software and is available with 2–16 channels of fully synchronous data-acquisition. Each channel has its own ADC and its own pre-amplifier, with either 8 or 16 bit resolution and sampling rates up to 200 MS/s. In addition, Spectrum has announced the first product to be based on its new, ultra-fast, modular M4i platform designed to meet the growing need for increased streaming bandwidth and higher sampling rates. The M4i.4451-x8 comes with four channels and 500 MS/s synchronous sampling speed at 14 bit ADC resolution. A smaller version is also available. For further information, tel +49 4102/6956 0, e-mail info@spec.de or visit www.spectrum-instrumentation.com.

XP Power has announced a 130 W addition to the ECS series of AC-DC power supplies. Packaged in a compact 50.8 × 101.6 × 31.8 mm open-frame format, the single output ECS130 can be either convection or forced-air cooled and used in a variety of end-applications. When convection cooled, the unit is capable of up to 100 W output. The series comprises six single-output models providing nominal output voltages from +12 to +48 VDC. The input accommodates the full universal voltage range from 80–264 VAC. The ECS130 meets ANSI/AAMI ES60601-1 and IEC60601-1 medical equipment safety standards and UL60950-1 / IEC60950-1 standards for IT and industrial equipment. For the data sheet, see http://download.publitek.com/XPE0171-SF_ECS65-130_070813.pdf. For further information, contact Steve Head, tel +44 118 984 5515, e-mail shead@xppower.com.

Meeting

The **Varenna School on Grid and Cloud Computing – Concepts and Practical Applications** will be held on 25–30 July in Varenna. Topics will cover the Worldwide LHC Computing Grid, past, present and future; clouds in the biosciences; scientific clouds; global networking; grid and cloud architecture; cloud middleware; big data – challenges and perspectives; data preservation; and grid and cloud monitoring. Lectures will be by major experts in grid and cloud computing from around the world. The deadline for applications is 5 May. For further information, visit http://en.sif.it/activities/fermi_school/mmxiv or contact Alina Grigoras, e-mail alina.gabriela.grigoras@cern.ch.

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.

Recruitment

Faculty positions at Inter-Institutional Centre for High Energy Physics, Madurai, India (Nodal Centre for India-based Neutrino Observatory)

Inter-Institutional Centre for High Energy Physics (IICHEP) is the Nodal Centre for the India-based Neutrino Observatory (INO). Located in the city of Madurai in south India, the IICHEP will be the nodal centre of the multi-institutional INO project, entrusted with building a large underground Laboratory, geared to take off soon. At present the IICHEP will be administered through the Tata Institute of Fundamental Research (TIFR), Mumbai. Once fully operational it is expected to become an autonomous research centre under Department of Atomic Energy, Govt. of India.

IICHEP expects to have faculty positions at the level of Reader in Pay Band-4 at its centre at Madurai soon. Selected scientists will be involved in the construction and operation of the neutrino detector (ICAL) that is coming up at the INO underground laboratory at Bodi West Hills, Tamil Nadu. They are also expected to participate in the analysis of data as well as in the R & D program for future detector development. Expertise related to particle detector development, associated electronics, data acquisition is desirable. Preference will be given to candidates having hardware and data analysis experience with large detector systems used in nuclear and particle physics. Positions are also available for phenomenologists with expertise in the area of neutrino physics and particle physics with experience in simulation and data analysis. In future, opportunities may exist to participate in other experiments related to dark matter detection, double beta decay etc that may come up at INO.

Applicant should have Ph.D. and 5 years of post-doctoral experience.

Exceptionally good candidate having less post-doctoral experience may be considered for Reader in Pay Band-3. Application along with CV, research interest as well as list of referees should be sent to **projdir.ino@tifr.res.in** as email attachment (preferred) or to Project Director, India-based Neutrino observatory, TIFR, Homi Bhabha Road, Mumbai 400005, India by mail.

IFAE INSTITUT DE FÍSICA D'ALTES ENERGIES
Consorci de la Generalitat de Catalunya
i de la Universitat Autònoma de Barcelona

"la Caixa" EXCELENCIA SEVERO OCHOA

"La Caixa – Severo Ochoa" predoctoral positions in Theoretical and Experimental Particle Physics, Astroparticle Physics, Cosmology and Instrumentation R&D at IFAE Barcelona.

The "Institut de Física d'Altes Energies" (IFAE) in Barcelona announces the opening of four predoctoral positions for outstanding young graduates interested in working towards a PhD thesis at IFAE. These positions are funded by the "La Caixa" Foundation under the Severo Ochoa Program for Scientific Excellence, a distinction recently awarded to IFAE.

The contracts will have a duration of four years (the typical time to prepare a PhD thesis at IFAE), and will enjoy competitive conditions, with a progressively increasing salary averaging 22.384 € per year.

Interested candidates with an excellent CV and willing to work in the areas of research of IFAE, namely, theoretical particle physics, experimental particle physics (ATLAS and T2K), astroparticle physics (MAGIC and CTA), observational cosmology (DES, PAU and Euclid) and instrumentation development (ATLAS upgrades and medical imaging), should fill an application form as described at:

http://www.ifae.es/eng/work/open-positions.html

and upload the requested information, which includes a cover letter, a CV, a one-page statement of interest, and the names and email addresses of two professors willing to provide reference letters.

The application deadline will be March 31, 2014. The review process will take place during April, and offers will be made in early May. In case of a positive evaluation, hiring will take place during September and October 2014.

General information about IFAE and its Severo Ochoa program is available at **http://www.ifae.es**.

UNIVERSITÉ DE GENÈVE

Post one:

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This is a full time tenured or tenure track (in the case of assistant professor) position. Duties include developing a research program at the highest international level, teaching at undergraduate and postgraduate level, and securing external funding. Moreover, the successful candidate will supervise master and doctoral thesis and will take up administrative and organizational duties at the department level.

REQUIREMENTS: PhD degree or equivalent.
Experience in research and teaching.
Publications in international top journals.

Applications including a CV, teaching and research statement and a complete list of publications must be submitted online before March 31st, 2014 at: **https://jobs.icams.unige.ch**. Complementary information may be obtained at the following e-mail address: **scienceopenings@unigech**.

Applications from women are particularly welcome.

Post two:

FULL PROFESSOR, Associate professor or Assistant professor in THEORETICAL PHYSICS

RESPONSIBILITIES: We are looking for an outstanding theoretical physicist with pronounced interest and expertise in applications of mathematical physics to condensed matter systems (examples are integrability and AdS/CMT). The candidate is capable of developing a broad and independent line of research in theoretical physics with interest to interact with mathematicians. She/he is expected to contribute to the excellent international scientific reputation of our physics section.

This is a full time tenured position (or tenure track in the case of an assistant professor). Duties include developing a research program at the highest international level, teaching at undergraduate and postgraduate level, and securing external funding. Moreover, the successful candidate will supervise master and doctoral thesis and will take up administrative and organizational duties at the departmental level.

REQUIREMENTS: PhD degree or equivalent.
Experience in research and teaching.
Publications in international top journals.

Applications including CV, research and teaching statement and a complete list of publications must be submitted online before March 31st, 2014 at: **https://jobs.icams.unige.ch**.Complementary information may be obtained at the following e-mail address: **scienceopenings@unige.ch**.

Applications from women are particularly welcome.

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- Experience with the operation of large and complex accelerator facilities
- Very good communication and team skills
- Basic knowledge of German is advantageous

For further information please contact Dr. Reinhard Brinkmann; phone +49 40 8998-3197, e-mail: reinhard.brinkmann@desy.de.

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Deadline for applications: 28th February 2014
www.desy.de

The Helmholtz Association is Germany's largest scientific organisation.
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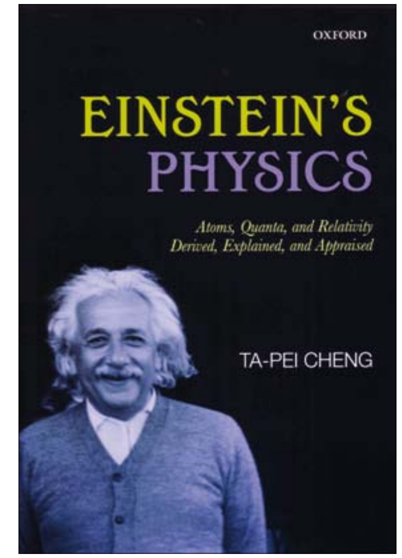
Bookshelf

Einstein's Physics: Atoms, Quanta, and Relativity – Derived, Explained, and Appraised

By Ta-Pei Cheng
Oxford University Press
Hardback: £29.99
Also available as an e-book



Being familiar with the work of Ta-Pei Cheng, I started this book with considerable expectations – and I enjoyed the first two sections. I found many delightful discussions of topics in the physics that came after Albert Einstein, as well as an instructive discussion on his contributions to quantum theory, where the author shares Einstein's reservations about quantum mechanics. However, the remainder of the text dedicated to relativity and related disciplines has problems. The two pivotal issues of special relativity, the aether and the proper time, provide examples of what I mean.

On p140, the author writes "...keep firmly in mind that Einstein was writing for a community of physicists who were deeply inculcated in the aether theoretical framework", and continues "(Einstein, 1905) was precisely advocating that the whole concept of aether should be abolished". Of course, Einstein was himself a member of the community "inculcated in the aether" and, indeed, aether was central in his contemplation of the form and meaning of physical laws. His position was cemented by the publication in 1920 of a public address on "Aether and the Theory of Relativity" and its final paragraph "…there exists an aether. According to the general theory of relativity space without aether is unthinkable; for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time...". This view superseded the one expressed in 1905, yet that is where the discussion in the book ends.

The last paragraph on p141 states that "...the key idea of special relativity is the new conception of time." Einstein is generally credited with the pivotal discovery of "body time", or in Hermann Minkowski's terminology, a body's "proper time". The central element of special relativity is the understanding of the invariant proper time. Bits and pieces of "time" appear in sections 9–12 of the book, but the term "proper time" is mentioned only incidentally. Then on p152 I read "A moving clock appears to run slow." This is repeated on p191, with the addition "appears to this observer". However, the word "appears" cannot be part of an unambiguous explanation. A student of Einstein's physics would say "A clock attached to a material body will measure a proper-time lifespan independent of the state of inertial motion of the body. This proper time is the same as laboratory time only for bodies that remain always at rest in the laboratory." That said, I must add that I have never heard of doubts about the reality of time dilation, which is verified when unstable particles are observed.

Once the book progresses into a discussion of Riemannian geometry and, ultimately, of general relativity, gauge theories and higher-dimensional Kaluza–Klein unification, it works through modern topics of only marginal connection to Einstein's physics. However, I am stunned by several comments about Einstein. On p223, the author explains how "inept" Einstein's long proof of general relativity was, and instead of praise for Einstein's persistence, which ultimately led him to the right formulation of general relativity, we read about "erroneous detours". On p293, the section on "Einstein and mathematics" concludes with a paragraph that explains the author's view as to why "...Einstein had not made more advances…". Finally, near the end, the author writes on p327 that Einstein "could possibly have made more progress had he been as great a mathematician as he was a great physicist". This is a stinging criticism of someone who did so much, for things he did not do.

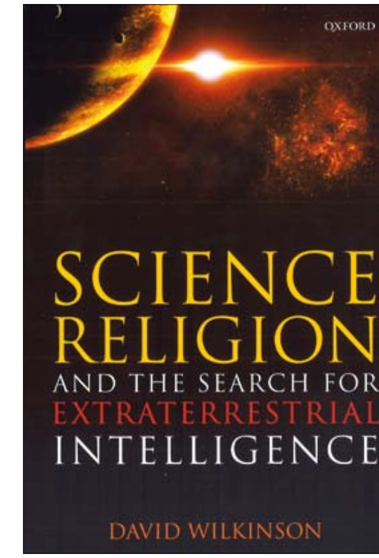
The book presents historical context and dates, but the dates of Einstein's birth and death are found only in the index entry "Einstein", and there is little more about him to be found in the text. A listing of 30 cited papers appears in appendix B1 and includes only three papers published after 1918. The book addresses mainly the academic work of Einstein's first 15 years, 1902–1917, but I have read masterful papers that he wrote during the following 35 years, such as "Solution of the field of a star in an expanding universe" (Einstein and Straus 1945 *Rev. Mod. Phys.* **17** 120 and 1946 *Rev. Mod. Phys.* **18** 148).

I would strongly discourage the target group – undergraduate students and their lecturers – from using this book, because in the part on special relativity the harm far exceeds the good. To experts, I recommend Einstein's original papers.

● *Johann Rafelski, University of Arizona.*

Science, Religion, and the Search for Extraterrestrial Intelligence

By David Wilkinson
Oxford University Press
Hardback: £25
Also available as an e-book



With doctorates in both astrophysics and theology, David Wilkinson is well qualified to discuss the subject matter of this book. He provides a captivating narrative on the scientific basis for the search for extraterrestrial intelligence and the religious implications of finding it. However, the academic nature of the writing might hinder the casual reader, with nearly every paragraph citing at least one reference.

Bookshelf

Scientific and religious speculation on the possibility of life elsewhere in the universe is age-old. Wilkinson charts its history from the era of Plato and Democritus, where the existence of worlds besides our own was up for debate, to the latest data from telescopes and observatories, which paint vivid pictures of the many new worlds discovered around alien suns.

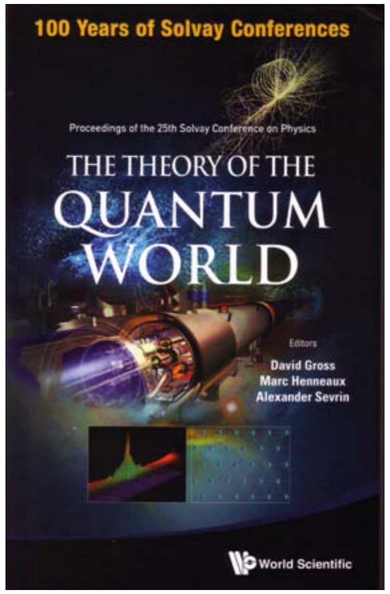
Readers familiar with astrophysics and evolutionary biology might find themselves skipping sections of the book that go into the specific conditions that need to be met for Earth-like life to evolve and attain intelligence. Wilkinson, however, is able to tie these varied threads together, presenting both the pessimism and optimism towards the presence of extraterrestrial life exhibited by scientists from different fields.

Despite referring to religion in the title, Wilkinson states early on that his work mainly discusses the relationship of Christianity and SETI. In this regard, the book provided me with much insight into Christian doctrine and its many – often contradictory – views on the universe. For example, despite the shaking of the geocentric perspective with the so-called Copernican Revolution, some Christian scholars from the era maintained that the special relationship of humans with God dictated that only Earth could harbour God-fearing life forms. Earth, therefore, retained its central position in the universe in a symbolic if not a literal sense. Other views held that nothing could be beyond the ability of an omnipotent, omnipresent God, who to showcase his glory might well have created other worlds with their own unique creatures.

After covering everything from science fiction to Christian creation beliefs, Wilkinson concludes with his personal views on the value of involving theology in searches for alien life. I leave you to draw your own conclusions about this! Overall, the book is a fascinating read and is recommended for those pondering the place of humanity in our vast universe.

● *Achintya Rao, CERN.*

The Theory of the Quantum World: Proceedings of the 25th Solvay Conference on Physics
By David Gross, Marc Henneaux and Alexander Sevrin (eds.)
World Scientific
Hardback: £58
Paperback: £32
E-book: £24



Since 1911, the Solvay Conferences have helped shape modern physics. The 25th edition in October 2011, chaired by David Gross, continued this tradition, while also celebrating the conferences' first centennial. The development and applications of quantum mechanics have been the main threads throughout the series, and the 25th Solvay Conference gathered leading figures working on a variety of problems in which quantum-mechanical effects play a central role.

In his opening address, Gross emphasized the success of quantum mechanics: "It works, it makes sense, and it is hard to modify." In the century since the first Solvay Conference, the worry expressed by H A Lorentz in his opening address in 1911 – "we have reached an impasse; the old theories have been shown to be powerless to pierce the darkness surrounding us on all sides" – has been resolved. Physics is not in crisis today, but as Gross says there is "confusion at the frontiers of knowledge". The 25th conference therefore addressed some of the most pressing open questions in the field of physics. As Gross admits, the participants were "unlikely to come to a resolution during this meeting….[but] in any case it should be lots of fun".

The proceedings contain the rapporteur talks and, in the Solvay tradition, they also include the prepared comments to these talks. The discussions among the participants — some involving dramatically divergent points of view — have been carefully edited and are reproduced in full.

The reports cover the seven sessions: "History and reflections" (John L Heilbron and Murray Gell-Mann); "Foundations of quantum mechanics and quantum computation" (Anthony Leggett and John Preskill); "Control of quantum systems" (Ignacio Cirac and Steven Girvin); "Quantum condensed matter" (Subir Sachdev); "Particles and fields" (Frank Wilczek); and "Quantum gravity and string theory" (Juan Maldacena and Alan Guth). The proceedings end – as did the conference – with a general discussion attempting to arrive at a synthesis, where the reader can judge if it fulfilled the prediction by Gross and was indeed "lots of fun".

Books received

Mathematics of Quantization and Quantum Fields
By Jan Dereziński and Christian Gérard
Cambridge University Press
Hardback: £90 $140
Also available as an e-book

Unifying a range of topics currently scattered throughout the literature, this book offers a unique review of mathematical aspects of quantization and quantum field theory. The authors present both basic and more advanced topics in a mathematically consistent way, focusing on canonical commutation and anti-commutation relations. They begin with a discussion of the mathematical structures underlying free bosonic or fermionic fields, such as tensors, algebras, Fock spaces, and CCR and CAR representations. Applications of these topics to physical problems are discussed in later chapters.

Three-Particle Physics and Dispersion Relation Theory
By A V Anisovich, V V Anisovich, M A Matveev, V A Nikonov, J Nyiri and A V Sarantsev
World Scientific
Hardback: £65
E-book: £49

The necessity of describing three-nucleon and three-quark systems has led to continuing interest in the problem of three particles. The question of including relativistic effects appeared together with the consideration of the decay amplitude in the dispersion technique. The relativistic dispersion description of amplitudes always takes into account processes that are connected to the reaction in question by the unitarity condition or by virtual transitions. In the case of three-particle processes they are, as a rule, those where other many-particle states and resonances are produced. The description of these interconnected reactions and ways of handling them is the main subject of the book.

Viewpoint

Greater than the sum of the parts

The president of Council offers a personal insight into the continuing attraction of collaboration with CERN.

Agnieszka Zalewska, president of CERN Council. (Image credit: Andrzej Zalewska.)

CERN was founded in 1954 with the aim of bringing European countries together to collaborate in scientific research after the horrors of the Second World War. After the war, however, Europe had been divided politically by the "Iron Curtain", and countries in the Eastern Bloc were not in a position to join CERN. Nevertheless, through personal contacts dating back to pre-war days, scientists on either side of the divide were able to keep in touch. From the start, CERN had schemes to welcome physicists from outside its member states. At the same time, the bubble-chamber experiments in particular provided a way that research groups in the East could contribute to physics at CERN from their home institutes. The groups could analyse bubble-chamber events with relatively few resources and make their mark by choosing specific areas of analysis.

In the case of my country, Poland, this contact with CERN from the 1950s provided a precious window on modern science, allowing us to maintain a good level in particle physics. The first Polish physicist was welcomed to the laboratory in 1959 and was soon followed by others when CERN awarded several scholarships to young researchers from Cracow and Warsaw. Collaboration between CERN and Polish institutes followed, and despite the difficult circumstances, physicists in Poland were able to make important contributions to CERN's research programmes. In 1963, the country gained observer status at CERN Council, as the only country from Eastern Europe.

My association with CERN began when I was a student at the Jagellonian University in Cracow in the early 1970s, working on the analysis of events collected by the 2-m bubble chamber. During the 1960s, the experimental groups in Cracow and Warsaw had made the analysis of high-multiplicity events their speciality, and this was the topic for my doctoral thesis. The collaborative work with CERN gradually extended to electronic detectors, and from the 1970s Polish groups contributed hardware such as wire chambers to a number of experiments. The DELPHI experiment at the Large Electron–Positron (LEP) collider already used a variety of Polish contributions to both hardware and software.

The start-up of LEP coincided with the big political changes in Eastern Europe at the end of the 1980s. Poland became the first former Eastern Bloc country to be invited to become a CERN member state, and in July 1991 my country became the 16th member of CERN – a moment of great pride. Hungary, the Czech Republic and Slovakia followed soon after.

The end of the 1980s also coincided with the development of the World Wide Web to help the large collaborations at LEP work together. It revolutionized the way we could work in our home institutions. In particular in Poland, a dedicated phone line set up in 1991 between CERN and the institutes in Cracow and Warsaw provided a "magic" link, allowing us, for example, to make changes remotely to software running underground at LEP.

It is hard today to imagine the world without the web. It was CERN's gift to humanity – creating connections, allowing the exchange of ideas and communication between people all over the world. Developed in a scientific, non-commercial organization, the web's international annual economic value is now estimated at €1.5 trillion. As Chris Llewellyn Smith, CERN's director-general from 1994 to 1998, asked: how many yearly budgets of CERN have been saved because it was developed quickly in a non-commercial environment?

Now, after some four decades in particle physics, I have the enormous privilege to be president of CERN Council. I have already experienced the exceptional moment when the Israeli flag was raised for the first time at the Meyrin entrance to the laboratory, representing the first new member state to join the organization for 14 years. Other countries are at various stages in the process of accession to become member states or to attain associate membership. In discussions with the physicists from these countries, I recognize the same feelings that we had in countries like Poland in the 1960s or 1970s.

As one person said to me recently, it is not only CERN as the organization, but the idea of CERN that has such a strong appeal. It brings people together from different nationalities and cultures, people who have different ways of doing things – and this brings added value. CERN really is something where the whole is greater than the sum of the parts, as we all work together towards a common goal – a noble goal – to learn more about the universe that we inhabit.

During the past 60 years, the idea of CERN has succeeded in the goal of bringing European countries to work peacefully together, helping to bridge the divisions that existed between East and West. I sincerely believe that this "idea" will continue to inspire people around the world for years to come.

● *Agnieszka Zalewska, CERN Council president and H Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences.*

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News from the Desktop and NIM/Desktop High Voltage Power Supply
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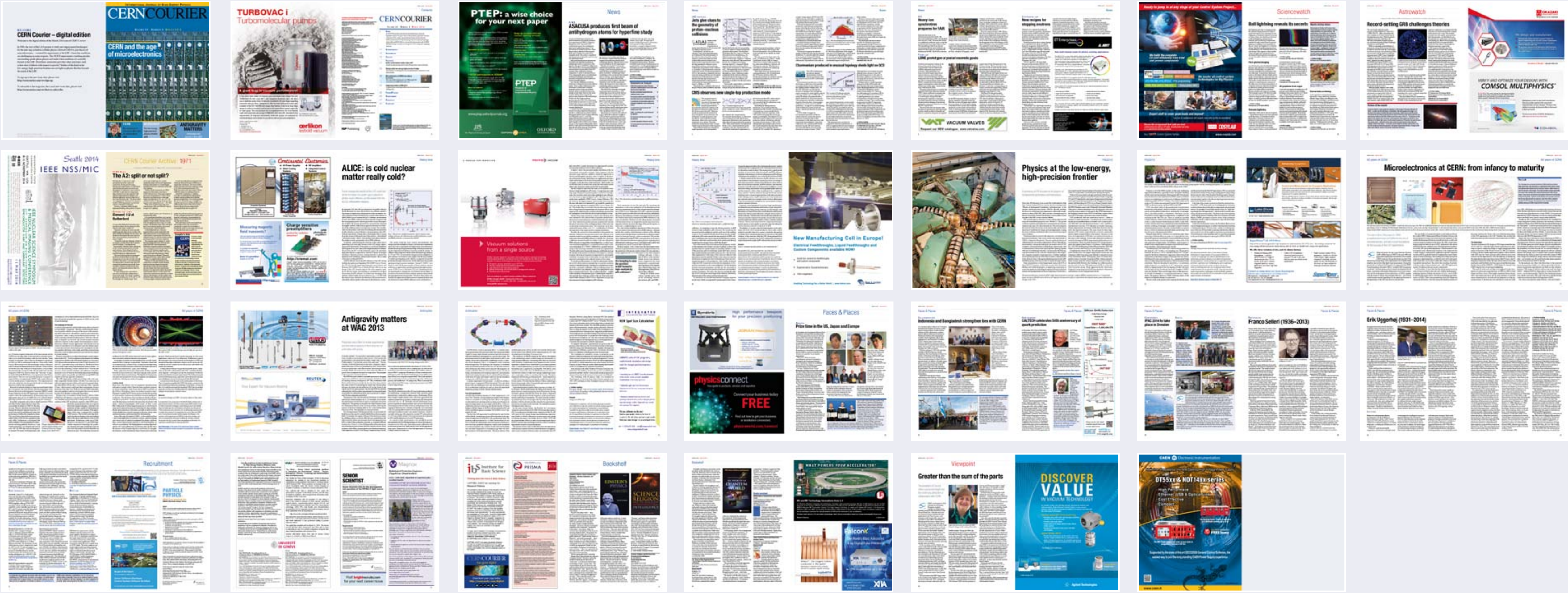

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