WELCOME

CERN Courier – digital edition

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

The Standard Model is coming under more and more pressure from experiments. In particular, new results from the analysis of LHC's Run 1 data show discrepancies, or "tensions", with the theoretical predictions. For the time being, they are all of the 2–3σ variety but, if confirmed at Run 2, they would be the signatures of new physics at the TeV scale. In the experimental sector, we direct our attention to the improved techniques of nuclear emulsions, which could also be used for the next generation of neutrino experiments. Finally, in this issue we feature the Canfranc Underground Laboratory, one of the four deep-underground laboratories where, besides astroparticle physics, scientists also carry out geology and biology studies.

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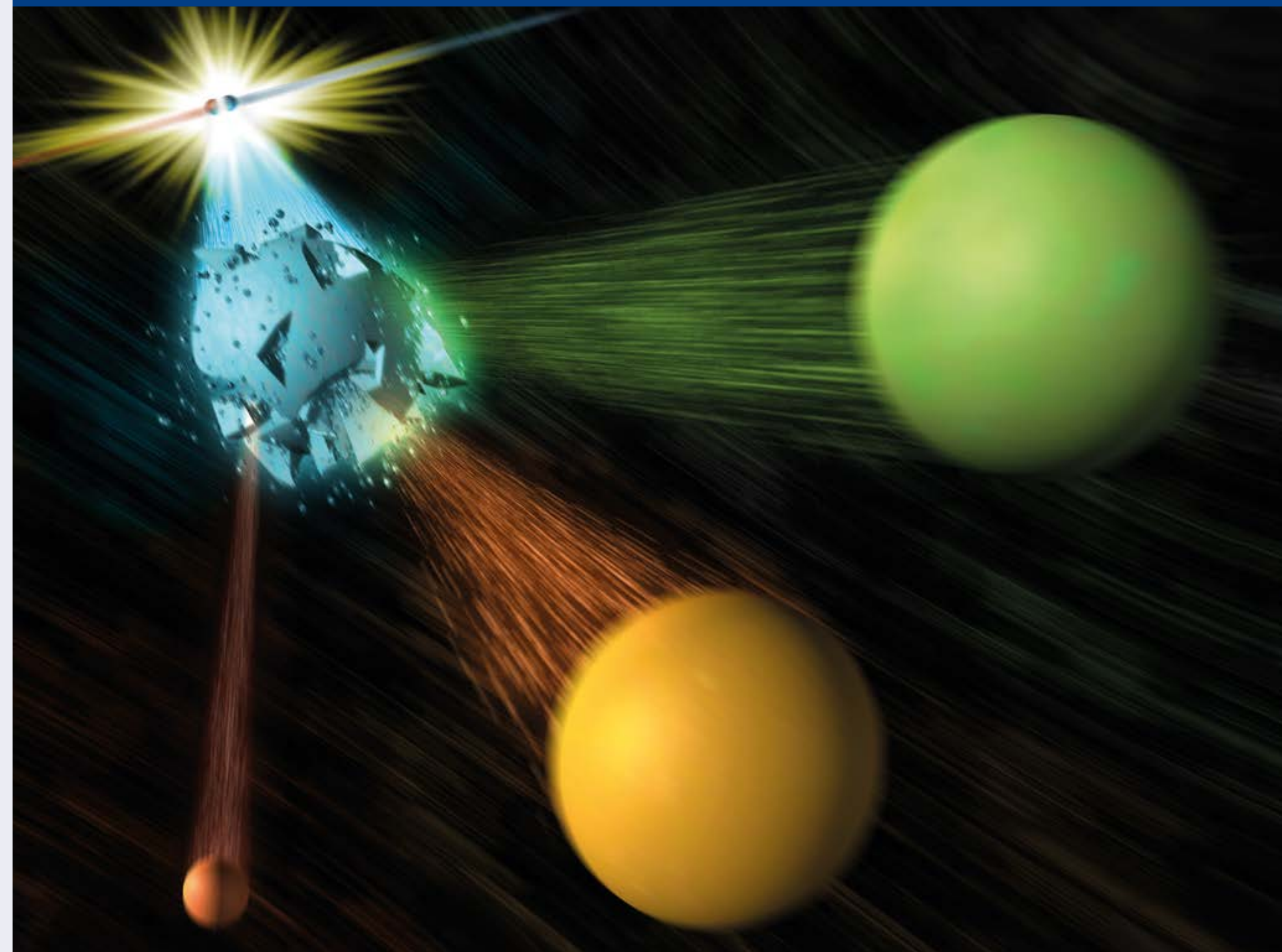
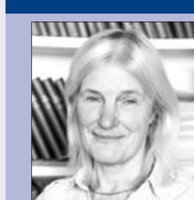


Tensions in the Standard Model



OUR COURIER

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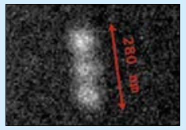


On the cover: Conceptual art illustrating the decay, $B \to D^* \tau\nu$, of a heavy meson (containing a b quark) to a final state containing a charmed particle and a tau lepton. This decay was measured in 2012 by the BaBar experiment to have a rate that was somewhat higher than expected in the Standard Model, and subsequent results from Belle and LHCb have supported this tension. Other such hints are discussed in the article on p21. (Image credit: Greg Stewart, SLAC.)

Viewpoint

Maintaining an ideal

The former editor reflects on the role of *CERN Courier* in a changing news environment.

Image credit: CERN.

Christine Sutton edited CERN Courier *from January 2003 to October 2015, when she retired from CERN. She was the magazine's sixth editor since it began under Roger Anthoine in 1959.*

By Christine Sutton

August 1959 saw the first issue of *CERN Courier* – "the long-expected internal bulletin" and idea of Cornelis Bakker, who was then CERN's Director-General. The goals stated on the first page included the aim to "maintain the ideal of European co-operation and the team spirit which are essential to the achievement of our final aim: scientific research on an international scale" (*CERN Courier* July/August 2009 p30).

From that very first issue, the *Courier* contained news about other labs – "Other people's atoms" – and the cover soon dropped the tag line "Published monthly for CERN staff members" as outside interest grew rapidly. Following a readership survey that showed a thirst for "more news from other laboratories", the magazine's 10th anniversary year saw the introduction of the laboratory correspondents – a concept that was formalised further in 1975, after a meeting on "Perspectives in High Energy Physics" in New Orleans, attended by lab directors and senior scientists from Europe, Japan, the US and the USSR.

One topic at the meeting concerned international communication in high-energy physics, and here CERN proposed that the *Courier* could do more, with the help of more active participation from the other labs plus local distribution in several countries. The issue for January 1976 saw the subtitle "Journal of High-Energy Physics" discreetly positioned inside the front cover above the list of distribution centres and lab correspondents. Five years later, an editorial advisory panel was named for the first time, and the subtitle extended to "International Journal of the High-Energy Physics Community".

Changing times

That was 35 years ago, and since then *CERN Courier* has developed through mainly incremental changes to its content. Book reviews, opinion pieces ("Viewpoint"), "Astrowatch", "Sciencewatch" and an archive page have become regular items, and feature articles, in particular, are signed by the authors. The "look and feel" of the magazine has also changed, from being predominantly black and white to being full colour since IOP Publishing took charge of production. But the basic aim has remained the same, as the *Courier* has continued to serve an international high-energy readership, with the help of enthusiastic support from the worldwide community.

Over the same period of time, high-energy physics has seen many remarkable developments. The discoveries of the gluon at DESY, of the W and Z bosons at CERN, and of the top quark at Fermilab provided essential pieces of the Standard Model, with the new boson observed at the LHC in 2012 revealing the final keystone associated with the Brout–Englert–Higgs mechanism for giving mass to elementary particles. Meanwhile, the centre-of-gravity of the field has moved slowly but surely from the US to Europe and CERN, with the LHC currently exploring and extending the high-energy frontier.

In addition, the way that scientists communicate has changed dramatically, largely as a result of the internet, the World Wide Web instigated at CERN by Tim Berners-Lee, and arXiv – the electronic preprint repository created by Paul Ginsparg, which became accessible through the web in 1993. Of course, this has been only part of a communication revolution in which information – and, indeed, mis-information – is today transmitted almost immediately, in formats varying from official press releases to informal blogs and tweets.

A new world

These developments have also transformed the way that new results are communicated. Even results in a journal with strict embargoes, such as *Nature*, are flashed around the world the instant the embargo lifts, quickly propagating through science news channels and social media. Against this background, news in *CERN Courier* – and, as is increasingly the case, results presented at conferences – can be "old hat". So where does that leave this magazine?

When I started as editor in 2003, I had a dream to be able to say "you read it first in *CERN Courier*" – an idea that was really already dead. Today, a more realistic goal would be to say "for the story behind the headlines, read *CERN Courier*". ArXiv and open-access publishing make preprints and papers readily accessible to anyone who savours the details of a specific piece of research; nevertheless, there will always be other people who would like a simpler but authoritative summary.

In *Physics in the 20th Century*, CERN's former Director-General Victor Weisskopf wrote "…it is beneficial to the scientist to attempt seriously to explain scientific work to a layman or even to a scientist in another field. Usually, if one can not explain one's work to an outsider, one has not really understood it." This is, in my opinion, just as true for specialities within a field such as high-energy physics, so it seems to me that *CERN Courier* should long continue, and so "maintain the ideal of European co-operation and…achievement of our final aim: scientific research on an international scale".

News

CERN

A wealth of data for physics from the LHC: 1400 colliding bunches per beam and counting

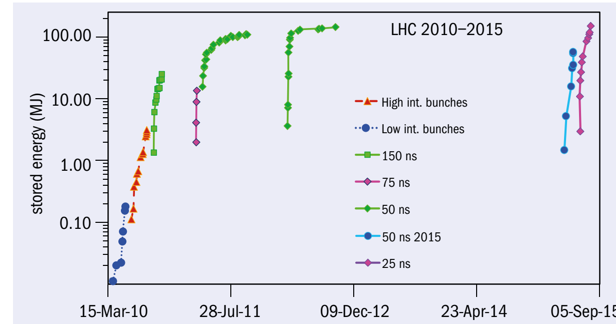
Thanks to the work done during the LHC machine-development period and technical stop at the end of the summer, the LHC is enjoying a stable-intensity ramp-up period, which is giving experiments precious data for their physics programmes.

During the machine-development break at the end of August, a variety of measurement and development programmes were carried out in the machine. They included tests for exploring the limits of smaller beam sizes at the interaction points and studies of collimation using bent crystals. Highlights also included the validation of a 40 cm β*, which effectively doubles the luminosity potential of the present set-up. Free from the challenges of high beam intensity, machine availability was high during this remarkably successful machine-development period.

This period was followed by a five-day technical stop. The key objectives were modifications to the critical Quench Protection System, the consolidation of the cooling and electrical-distribution systems, and important maintenance work on the cryogenics system. A huge number of activities were involved to make the technical stop a success.

The effort paid off: since the end of the technical stop, the LHC has gone smoothly through a complete validation period with beam, which ensures that the machine is ready for the intensity ramp-up from a machine-protection standpoint.

The validation is obtained step-by-step and with increasing intensity, both in terms of the number of bunches and the particles in each bunch. The first step consists of running through a full LHC cycle, from injection to collisions and beam dump. This is done initially with a low-intensity bunch ("probe") to check all of the machine settings and equipment. This phase is followed by a series of collimation- and absorber-validation tests at different points in the LHC cycle. Low-intensity beams – typically the equivalent of three nominal bunches (3×10^{11} protons) – are expanded transversely or longitudinally, or are de-bunched to verify that the collimators and absorbers are correctly intercepting lost particles.



The graph shows the evolution of stored energy per LHC beam, over time. At the end of September, the energy stored in each beam reached the record-breaking value of 150 MJ.

The techniques for those validations have been improved progressively, and they can now be performed within 24 h in a few machine cycles.

As soon as the protection systems were validated with the probe beam, the intensity of the beam was ramped up in three steps to 459 bunches per beam – the level that had been reached before the summer stop. Further intensity ramp-ups are performed stepwise: at each step, the LHC must be operated for at least three periods of stable collisions. This is equivalent to integrating at least 20 h of operation before the next intensity step can be authorised. At each step, operators carefully analyse the data collected across many systems, in particular those related to machine protection, and give the green light for an intensity step only when all of the systems show satisfactory performance.

Following this scheme, about 10 days after the end of the break, the machine could be operated with around 1000 bunches per beam and 25 ns bunch spacing, which is the LHC design bunch spacing.

In the present beam configuration, the electron-cloud activity is still significant and considerable power is deposited onto the vacuum-chamber beam screen. For good performance of the machine, the beam-screen temperature should remain below 30 K, and this is achieved by managing the heat-load transients. This operation is particularly delicate for the cryogenic-system operation team in the CERN Control Centre during the injection and energy ramp-up of beams.

The beam intensity of Run 2 can also be measured in terms of the energy stored in each beam: with more than 1000 bunches per beam, the stored energy in each beam exceeds 100 MJ. Towards the end of September, the machine reached 150 MJ, breaking the record of Run 1 (140 MJ).

Sommaire en français

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LHC EXPERIMENTS

CMS observes long-range correlations in pp collisions at 13 TeV

The CMS collaboration has published its first particle-correlation result from proton–proton (pp) collisions at a centre-of-mass energy of 13 TeV. The paper describes the observation of a phenomenon first seen in nucleus–nucleus collisions, and also detected by CMS in 2010 in the initial LHC pp collision run, at a centre-of-mass energy of 7 TeV. CMS later also observed the phenomenon in proton–lead (pPb) collisions at a centre-of-mass energy of 5 TeV per nucleon pair. The phenomenon is an unexpected correlation between pairs of particles appearing in so-called high-multiplicity collisions, which are collisions that produce a large number of particles, i.e. approximately more than 100 charged particles with transverse momentum $p_T > 0.4$ GeV/c within the pseudorapidity region $|\eta| < 2.4$. The correlation manifests itself as a ridge-like structure in a 2D angular correlation function.

Following the CMS observation at 7 TeV, interest was expressed concerning the dependence of this phenomenon on the centre-of-mass energy. To more readily address this question, CMS collected a special 13 TeV data set, with an integrated luminosity of 270 nb^{-1}. Here, the average number of simultaneous collisions in a beam bunch crossing was as low as about 1.3, presenting conditions similar to those used for the 7 TeV analysis. Because the effect is expected to appear only in high-multiplicity events, a special trigger was developed based on the number of charged particles detected in the silicon tracker system.

Indeed, about once in every 3000 pp collisions with the highest produced particle multiplicity at 13 TeV, CMS observes an enhancement of particle pairs with small relative azimuthal angle $\Delta\phi$ (figure 1). It therefore appears that charged particles have a slight preference to be emitted pointing in nearly the same azimuthal direction, even if they are very far apart in terms of polar angle, which is measured by the quantity η.

Such correlations are reminiscent of effects first seen in nucleus–nucleus collisions at Brookhaven's RHIC and later in collisions of lead–lead nuclei (PbPb) at the LHC. Nucleus–nucleus collisions produce a hot, dense medium similar to the quark–gluon plasma thought to have existed in the first microseconds after the Big Bang. The long-range correlations in PbPb collisions are interpreted to result from a hydrodynamic expansion of this medium. Such a medium was not expected in the simpler pp system, and therefore the CMS results from 2010 led to a variety of theoretical models aiming for an explanation.

Remarkably, the new 13 TeV results demonstrate that, within the experimental uncertainties, the strength of the correlation (expressed in terms of associated particle yield) does not depend on the centre-of-mass energy of the pp collision but only on the particle multiplicity. This lack of energy dependence is similar to what is observed for hydrodynamic-flow coefficients measured in nucleus–nucleus collisions at RHIC and the LHC. Compared with the pp results, pPb and PbPb collisions produce correlations that are four and 10 times stronger, respectively, but which are qualitatively very similar to the pp results. The new results from pp collisions extend the measurements to much higher multiplicities compared with those at 7 TeV, and provide the opportunity to understand this curious phenomenon better.

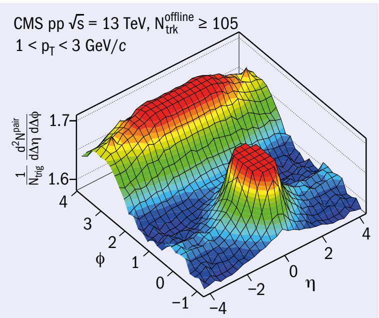


Fig. 1. 2D two-particle correlation function in pp collisions at $\sqrt{s} = 13$ TeV for pairs of charged particles, with each particle in the transverse-momentum range $1 < p_T < 3$ GeV/c. Results are shown for a high-multiplicity sample. The sharp peak from jet correlations around $(\Delta\eta, \Delta\phi) = (0, 0)$ is truncated to better exhibit the long-range correlation at $\Delta\phi \approx 0$.

● **Further reading**
cds.cern.ch/record/2056346

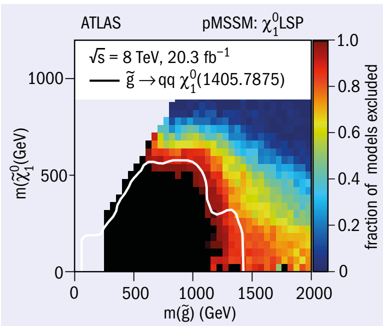
Supersymmetry searches: the most comprehensive ATLAS summary to date

ATLAS has summarised 22 Run 1 searches, using more than 310,000 models to work out where the elusive SUSY particles might be hiding.

The first run of the LHC taught us at least two significant things. First, that there really is a Higgs boson, with properties broadly in line with those predicted by the Standard Model. Second, that the hotly anticipated supersymmetric (SUSY) particles – which were believed to be needed to keep the Higgs boson mass under control – have not been found.

If, as many believe, SUSY is the solution to the Higgs-mass problem, there should be a heavy partner particle for each of the familiar Standard Model fermions and bosons. So why have we missed the super partners? Are they not present at LHC energies? Or are they just around the corner, waiting to be found?

ATLAS has recently taken stock of its progress in addressing the question of the missing SUSY particles. This herculean task examined an astonishing 500 million different models, each representing a possible combination of SUSY-particle masses. The points were drawn from the 19 parameter "phenomenological Minimal Supersymmetric Standard Model (pMSSM)" and concentrated on those models that can contribute to the cosmological dark matter.



The fraction of pMSSM points excluded by the combination of 8 TeV ATLAS searches in the plane of the gluino mass vs the mass of the lightest neutralino. The colour scale indicates the fraction of pMSSM points excluded in each mass bin, with black squares indicating 100% of model points being excluded.

The ambitious project involved the detailed simulation of more than 600 million high-energetic proton–proton collisions, using the power of the LHC computing grid. Teams from 22 individual ATLAS SUSY searches examined whether they had sensitivity to each of the 310,000 most promising models. This told them which combinations of SUSY masses have been ruled out by the ATLAS Run 1 searches and which masses would have evaded detection so far.

The results are illuminating. They show that in Run 1, ATLAS had particular sensitivity to SUSY particles with sub-TeV masses and with strong interactions. Their best constraints are on the fermionic SUSY partner of the gluon and, to a lesser extent, on the scalar partners of the quarks. Weakly interacting SUSY particles have been much harder to pin down, because those particles are produced more rarely. The conclusions are broadly consistent with those obtained using simplified models, which are being used to guide Run 2 SUSY searches.

The paper goes on to examine the knock-on effects of the ATLAS searches for other experiments. The ATLAS searches constrain the SUSY models that are being hunted by underground searches for dark-matter relics, and by indirect searches, including those measuring rare B-meson decays and the magnetic moment of the muon.

Today, the higher-energy of the 13 TeV LHC is bringing increased sensitivity to rare processes and to higher-mass particles. The ATLAS physics teams are excited to be using their fresh knowledge about where SUSY might be hiding to start the hunt afresh.

● **Further reading**
ATLAS Collaboration 2015 Summary of the ATLAS experiment's sensitivity to supersymmetry after LHC Run 1 – interpreted in the phenomenological MSSM arXiv.org/abs/1508.06608 submitted to *JHEP*.

LHCb determines the electroweak mixing angle

The electroweak mixing angle, θ_W, is a fundamental parameter of the Standard Model; it quantifies the relative strengths of electromagnetism and the weak force, and governs the Z-boson couplings to fermions. It is also something of a puzzle. The two most accurate determinations of the angle, carried out at LEP and SLD, are some three standard deviations different. More recent determinations at the Tevatron experiments, and by ATLAS and CMS at the LHC, have started to probe the difference. Now, LHCb has published a measurement based on LHC data taken in the forward region.

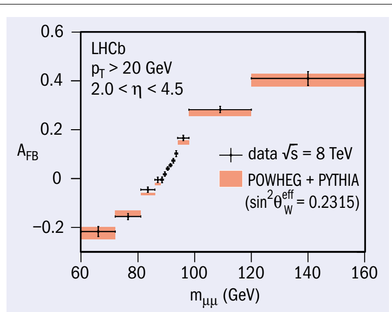


Fig. 1. An example of the angular asymmetry, for data taken at 8 TeV centre-of-mass energies: measurement points are compared with Standard Model predictions (shaded).

LHCb has measured the asymmetry in the angular distribution of muons in dimuon final states, A_{FB}, as a function of dimuon mass. The asymmetry depends on the squared sine function of the electroweak mixing angle, $\sin^2\theta_W$, and can be used to determine a value for it once the directions of the interacting quark and antiquark, needed to define the sign of the asymmetry, are known. LHCb's unique kinematic region benefits the analysis; dilution of the asymmetry is reduced as the incoming quark direction can be identified correctly 90% of the time, and theoretical uncertainties due to parton-density functions are lower than in the central region. In addition, LHCb's ability to swap the direction of its magnetic field allows many valuable cross-checks to be performed.

An example of the angular asymmetry, for data taken at 8 TeV centre-of-mass energies, is shown in figure 1 (p9) as measurement points compared with a (shaded) Standard Model prediction. The effective electroweak mixing angle is found by comparing this asymmetry distribution with a series of Standard Model templates, corresponding to a range of values of angle, and choosing the one that best matches data. The analysis is performed on both the 7 and 8 TeV data sets, and the results are combined. The corresponding value of $\sin^2\theta^{\rm eff}_{\rm W}$ is determined to be 0.23142±0.00073 (stat.)±0.00052 (sys.)±0.00056 (theory).

The value is one of the most precise measurements obtained at a hadron collider. Its accuracy is limited currently by statistics, and does not allow yet for a final word to be said on previous results from LEP, SLD, Tevatron and the LHC. In LHC Run 2 and beyond, there is scope to not just increase the number of events that can be analysed, but for improved parton-density functions (which dominate the theoretical error) to become available. The measurement should improve much further.

● **Further reading**
arxiv.org/abs/1509.07645

MEDICAL PHYSICS

Novel radionuclides to kill cancer

A new radiolabelled molecule obtained by the association of a ^{177}Lu isotope and a somatostatin-analogue peptide is showing potential as a cancer killer for certain types of tumour. It is being developed by Advanced Accelerator Applications (AAA), a radiopharmaceutical company that was set up in 2002 by Stefano Buono, a former CERN scientist. With its roots in the nuclear-physics expertise acquired at CERN, AAA started its commercial activity with the production of radiotracers for medical imaging. The successful commercial activity made it possible for AAA to invest in nuclear research to produce innovative radiopharmaceuticals.

^{177}Lu emits both a β particle, which can kill cancerous cells, and a γ ray, which can be useful for SPECT (Single-Photon Emission Computed Tomography) imaging. Advanced neuroendocrine tumours can be inoperable, and for many patients there are no therapeutic options. However, about 80% of all neuroendocrine tumours overexpress somatostatin receptors, and the radiolabelled molecule is able to selectively target those receptors. The new radiopharmaceutical acts by releasing the high-energy electrons after internalization in the tumour cells through the receptors. The tumour cells are destroyed by the radiation, and the drug is rapidly cleared from the body via urine. A complete treatment consists of only four injections, one every six to eight weeks.

The radiolabelled molecule is currently being used for the treatment of all neuroendocrine tumours on compassionate-use and named-patient basis in 10 European countries, and is seeking approval in both the EU and the US. A phase-III clinical trial (the NETTER-1 clinical study) conducted in 51 clinical centres in the US and Europe, is testing the product in patients with inoperable, progressive, somatostatin-receptor-positive, mid-gut neuroendocrine tumours. The results of this trial were presented on 27 September in a prestigious Presidential Session at the European Cancer Congress in Vienna, Austria. The NETTER-1 trial demonstrated that there is a statistically significant and clinically meaningful increase in progression-free survival in patients treated with the radiolabelled molecule, compared with patients treated under the current standard of care. The median progression-free survival (PFS) was not reached during the duration of the trial in the Lutathera arm and was 8.4 months in the comparative group ($p<0.0001$, hazard ratio: 0.21).

Another labelling radionuclide, the ^{68}Ga positron emitter, is a good candidate in the production of a novel radiotracer to be used in the precise diagnosis and follow-up of the family of diseases using PET (positron emission tomography).

SUBTERRANEAN EXPERIMENTS

XENON100 sees no evidence of dark-matter interactions with electrons in liquid xenon

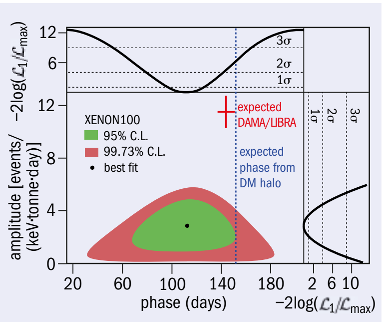
Nearly 400 days of data taken by the XENON collaboration were used to look for the telltale signature of dark matter, an event rate that varies periodically over the course of a year.

The null result of this search – the first of its kind using a liquid-xenon detector – strongly challenges dark-matter interpretations of the annual modulation observed by the DAMA/LIBRA experiments. Both subterranean experiments are operated at the Laboratori Nazionali del Gran Sasso (LNGS).

An annually varying flux of dark matter through the Earth is expected due to the Earth's orbital motion around the Sun, which results in a change of relative velocity between the Earth and the dark-matter halo thought to encompass the Milky Way. The observation of such an annual modulation is considered to be a crucial aspect of the direct detection of dark matter.

The DAMA/LIBRA experiments have observed an annual modulation of the residual rate in their sodium-iodide detectors since 1998. However, previous null results from several experiments searching for dark-matter-induced nuclear recoils, including XENON100, have challenged such an interpretation of the DAMA/LIBRA signal.

An alternative explanation, that the DAMA/LIBRA signal is instead due to dark-matter interactions with electrons, is challenged strongly by the new results from XENON100. In studies recently published in *Science* and *Physical Review Letters*, three models that predict dark-matter interactions



The XENON100 best-fit, 95% and 99.73% confidence-level contours as a function of amplitude and phase relative to 1 January 2011 for period P = 1 year. The expected DAMA/LIBRA signal with statistical uncertainties only and the phase expected from a standard dark-matter (DM) halo are overlaid for comparison. Top and side panels show −2log($\mathcal{L}_1/\mathcal{L}_{max}$) as a function of phase and amplitude, respectively, along with two-sided significance levels.

with electrons were considered. The very low rate of electronic recoils in XENON100 allowed these models to be ruled out with high probability.

The studies highlight the overall stability and low background of XENON100, a landmark performance achieved with this type of technology so far. Liquid-xenon detectors continue to lead the field of direct dark-matter detection in terms of their sensitivity to these rare processes. The commissioning of the next generation of XENON experiments at the underground site in LNGS is nearing completion. The detector, XENON1T, is expected to be 100 times more sensitive than its predecessor, and will hopefully shed more light on the elusive nature of dark matter.

● **Weblink**
arxiv.org/abs/1507.07748

NEUTRINO PHYSICS

Borexino finds evidence of neutrinos produced in the Earth's mantle

In July, the Borexino collaboration reported a geoneutrino signal from the Earth's mantle with 98% C.L. Geoneutrinos are electron antineutrinos produced by β decays of ^{238}U and ^{232}Th chains, and ^{40}K. These isotopes are naturally present in the interior of the Earth and have lifetimes compatible with the age of the planet. Their radioactive decays contribute significantly to the heat released by the planet. Therefore, the detection of antineutrinos can give geophysicists key information about the relative distribution of the various components in specific layers of the Earth's interior (crust and mantle).

In Borexino, geoneutrinos are detected in the 278 tonnes of ultra-pure organic liquid scintillator via the inverse β-decay process, $\bar{\nu}_e + p \rightarrow e^+ + n$, with a threshold in the neutrino energy of 1.806 MeV. Data reported in the recent publication were collected between 15 December 2007 and 8 March 2015 for a total of 2055.9 days before any selection cut. In this data set, the total geoneutrino signal (from the crust and mantle) has been measured for the first time at more than 5σ.

The signal disentanglement from background is obtained by applying selection cuts based on the properties of the interaction process. The combined efficiency of the cuts, determined by Monte Carlo techniques, is estimated to be (84.2±1.5)%. A total of 77 antineutrino candidates survived the cuts. They include signals from the Earth and background events. The latter are mainly composed of antineutrinos coming from the nuclear reactors. Their signal, corresponding to some 53 events, has been calculated and based on the data from the International Atomic Energy Agency. From previous studies, the contribution from the crust is estimated to be (23.4±2.8) terrestrial neutrino units (TNU), corresponding to 13 events. To estimate the significance of a positive signal from the mantle, the collaboration has determined the likelihood of S_{geo}(mantle) = S_{geo} − S_{geo}(crust) using the experimental likelihood profile of S_{geo} and a Gaussian approximation for the crust contribution. This approach gives a signal

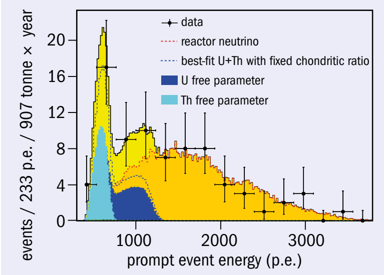


Fig. 1. Prompt light-yield spectrum, in units of photoelectrons (p.e.), of antineutrino candidates and best fit. The best fit shows the total contribution of geoneutrino, reactor neutrino and background (the yellow coloured area) and reactor neutrino (the orange coloured area). The result of a separate fit with U (the dark-blue area) and Th (the light-blue area) is also shown.

from the mantle equal to S_{geo}(mantle) = $20.9^{+15.1}_{-10.3}$ TNU (corresponding to 11 events), with the null hypothesis rejected at 98% C.L.

Although limited by the detection volume and the exposure time, the Borexino researchers could also perform spectroscopy studies (figure 1) that show how their detection technique allows separation of the contributions from uranium (the dark-blue area) and thorium (the light-blue area).

ASTROPARTICLE PHYSICS

CALET joins the International Space Station

After a spectacular launch from the Tanegashima Space Center on 19 August on board the Japanese H2-B rocket operated by the Japan Aerospace Exploration Agency (JAXA), the CALorimetric Electron Telescope (CALET) docked on the International Space Station on 24 August (EDT). From its privileged position at 400 km altitude, CALET will perform long-duration observations of high-energy charged particles and photons coming from space.

CALET is a space mission led by JAXA, with the participation of the Italian Space Agency and NASA. It is a CERN-recognised experiment and the second high-energy astroparticle experiment installed on the International Space Station (ISS) after AMS-02, which has been taking data since 2011. After berthing with the ISS, CALET was extracted by a robotic arm from the Japanese H-II transfer vehicle and installed on the external platform JEM-EF of the Japanese module. The instrument is now completing its check-out phase. Dedicated calibration runs will precede the start of the science data-taking period, which is expected to continue for several years.

CALET is a space observatory designed to identify electrons, nuclei and γ rays coming from space, and to measure their energies. A high-resolution measurement of the energy is provided by a deep, homogeneous calorimeter preceded by a high-granularity pre-shower calorimeter with imaging capabilities. To ensure very accurate calibration of the calorimetric instruments, the CALET collaboration has carried out several calibration tests at CERN, the most recent one in February 2015.

CALET's science programme includes measurement of the detailed shape of the electron spectrum above 1 TeV. High-energy electrons are expected to originate less than a few thousand light-years from Earth, because they are known to lose energy quickly when travelling in space. Their detection might be able to reveal the presence of nearby astronomical source(s) where electrons are accelerated. The high end of the spectrum will be particularly interesting to scientists because it will help to resolve the interpretation of the electron and positron spectra reported by AMS-02, and ▷

News

could provide a clue to possible signatures of dark matter.

Thanks to its excellent energy resolution and ability to identify cosmic nuclei from hydrogen to beyond iron, CALET will also be able to study the hadronic component of cosmic rays. The collaboration will investigate the deviation from a pure power law that has been observed recently in the energy spectra of light nuclei, extending the present data to higher energies and measuring accurately the curvature of the spectrum as a function of energy. CALET will also measure the abundance ratio of secondary to primary nuclei, an important ingredient to understand cosmic-ray propagation in the Galaxy.

After berthing with the ISS, CALET was extracted by robotic arm from the Japanese HTV-5 transfer vehicle and installed on the Japanese Exposure Facility (right), where it will start its first data-taking. (Image credit: NASA, JAXA.)

NEUTRINO PHYSICS

An improved measurement of θ_{13} from Daya Bay

The Daya Bay Reactor Neutrino Experiment has recently published a new measurement of the disappearance of electron antineutrinos emitted by nuclear reactors. The observation improves the precision of the mixing angle θ_{13} and the associated mass-squared difference $|\Delta m^2_{ee}|$ by almost a factor of two.

This is the first measurement obtained with the completed Daya Bay detector configuration consisting of eight modular antineutrino detectors, providing a total target mass of 160 tonnes. The gadolinium-doped organic liquid scintillator detects electron antineutrinos via inverse beta decay ($\bar{\nu}_e + p \rightarrow e^+ + n$). Oscillation converts some of the $\bar{\nu}_e$ to ν_μ and $\bar{\nu}_\tau$, reducing the $\bar{\nu}_e$ flux. Six commercial pressurised-water nuclear reactors (17.4 GW of thermal power in total) of the Daya Bay Nuclear Power Complex are an intense source, producing about 10^{21} electron antineutrinos per second. Four detectors located around 300 to 500 m from the reactors measure the initial $\bar{\nu}_e$ rate from the reactors, while four detectors at around 1.6 km from the reactors observe the subsequent disappearance.

This result builds on previous measurements by the Daya Bay and RENO experiments, which provided the first proof that θ_{13} is nonzero. The improved statistical precision came from a 3.6 times increase in exposure, generating a data sample of 1.2 million $\bar{\nu}_e$ interactions. The systematic uncertainties were also reduced through improved characterisation of the detectors and reduction of background.

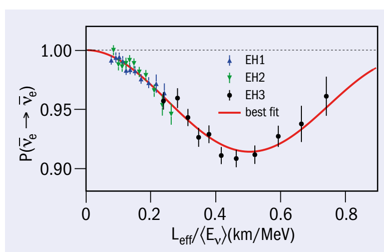


Fig. 1. The observed probability of reactor anti-ν_e disappearance versus the estimated proper time in the $\bar{\nu}_e$ rest frame shows clear evidence of neutrino oscillation. For this figure, the proper time is approximated using the average distance from reactor to detector, L_{eff}, divided by the mean $\bar{\nu}_e$ energy in each bin ($<E_\nu>$). The best-fit amplitude of the oscillation determined the mixing angle θ_{13}, while the frequency gives the mass-squared difference $|\Delta m^2_{ee}|$.

The analysis found $\sin^2(2\theta_{13}) = 0.084 \pm 0.005$ from the amplitude of anti-ν_e disappearance, while the energy dependence of this disappearance provided a measurement of oscillation frequency expressed in terms of the effective mass-squared difference $|\Delta m^2_{ee}| = (2.42 \pm 0.11) \times 10^{-3}\,\text{eV}^2$ (see figure 1). This is actually related to the two almost-equal neutrino mass-squared differences $|\Delta m^2_{31}|$ and $|\Delta m^2_{31}| = |\Delta m^2_{32} + \Delta m^2_{21}|$. One measure of how far neutrino physics has progressed is that the interpretation of this mixing parameter is now a step closer to being sensitive to the neutrino mass hierarchy. If the mass hierarchy is normal, then $|\Delta m^2_{32}| = (2.37 \pm 0.11) \times 10^{-3}\,\text{eV}^2$, while if it is inverted, $|\Delta m^2_{32}| = (2.47 \pm 0.11) \times 10^{-3}\,\text{eV}^2$.

The Daya Bay Reactor Neutrino Experiment continues to collect data, and aims at achiving a further factor of two improvement in precision by 2017.

● **Weblink**
dx.doi.org/10.1103/PhysRevLett.115.111802

***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.

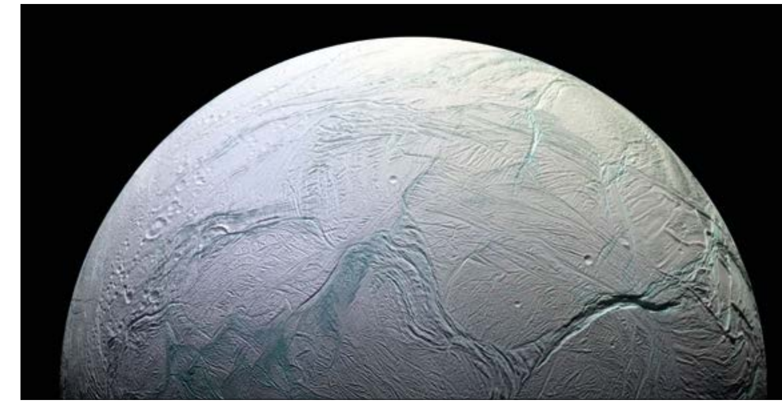
Sciencewatch

Compiled by John Swain, Northeastern University

Ocean on Enceladus

Enceladus, one of Saturn's (62!) moons, has a global sub-surface ocean. Using pictures from the Cassini probe, P C Thomas of Cornell University and colleagues observed the object's libration and found it so large as to imply a global ocean. Liquid water and vapour had been seen in jets from a south-polar depression, but the new work rules out a localised polar sea. Salts and organic material have been detected in the jets, so this now looks like an interesting place to search for life.

● **Weblink**
dx.doi.org/10.1016/j.icarus.2015.08.037



Saturn's moon Enceladus. (Image credit: NASA/JPL/Space Science Institute.)

Photonic molecules

Two photons can form a Coulomb bound state. This sounds, of course, ridiculous, because photons are uncharged, but M F Maghrebi of NIST/University of Maryland and colleagues took advantage of the photon coupling to Rydberg states via electromagnetically induced transparency, which provides an effective Coulomb potential, at least in theory. Such bound states could provide a means to couple to quantum information storied in photons for quantum computing, and it should be possible to couple arbitrarily many photons in this way.

● **Further reading**
M F Maghrebi *et al.* 2015 *Phys. Rev. Lett.* **115** 123601.

The farthest galaxy

The most distant galaxy yet observed is at $z = 8.68$, or more than 13.2 billion years old, dating just 600 million years from the start of our universe. Adi Zitran of Caltech and colleagues used the W M Keck Telescope in Mauna Kea, Hawaii, to discover the EGSY8p7 galaxy via its Lyman alpha emissions, with a significance of about 7.5 standard deviations. Further spectroscopic studies could help our understanding of early galaxy formation.

● **Further reading**
A Zitrin *et al.* 2015 *Astrophys. J. Lett.* **810** L12.

Artificial leaf

An artificial "leaf" can make fuels from carbon dioxide, and possibly compete with solar cells, capturing energy in the form of combustible chemicals instead of electricity. Eva M Nichols of the University of California in Berkeley and colleagues use a scheme coupling photoactive inorganic materials such as platinum, or α-NiS, to release hydrogen from water. The hydrogen is used, together with carbon dioxide, by micro-organisms, which produce methane with a Faradaic efficiency as high as 86%. The basic scheme could be generalised to use sunlight to synthesize more complex chemical products.

● **Further reading**
E M Nichols *et al.* 2015 *Proc. Nat. Acad. Sci.* **112** 11461.

Self-interfering clock

Interference experiments give us much of our information about fundamental physics, and now they can be done with a new twist: self-interfering clocks.

Ron Folman of Ben-Gurion University of the Negev in Beer-Sheva, Israel, and colleagues demonstrated the idea using Bose–Einstein condensates of about 10,000 ^{87}Rb atoms prepared in a superposition of two Zeeman states as clocks. The clock time serves as a "which-way" witness. Because in standard quantum mechanics, time is a global parameter, but in general relativity it is local proper time that matters, this opens new avenues to understanding the interplay between quantum mechanics and gravity.

● **Further reading**
Y Margalit *et al.* 2015 *Science* **349** 1205.

X-ray laser

A stable atomic narrow-band X-ray laser has reached the shortest wavelength ever: 1.5 Å, and about 10 times shorter than had been previously achieved.

Hitoki Yoneda of the University of Electro-Communications in Tokyo and the RIKEN SPring-8 Center in Hyogo, Japan, and colleagues used a photoionisation-pumping scheme proposed back in 1967, where an X-ray photon from a pump pulse removes an inner shell 1s electron from a copper atom, effectively making it an excited medium in which amplified spontaneous emission (ASE) can occur, with photons emitted from 2p electrons that fall to 1s. A second "seed" X-ray photon, tuned to the correct wavelength, is then sent in to be amplified. This is a proof of principle, with a rather low (2%) efficiency, but wavelength stability, which could make this sort of laser competitive with X-ray free-electron lasers in the future.

● **Further reading**
H Yoneda *et al.* 2015 *Nature* **524** 446.

Astrowatch

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

Massive black-hole pair is on fast-merger track

Earlier this year, astronomers discovered what appeared to be a pair of supermassive black holes (SMBHs) circling towards a collision, which would send out a burst of gravitational waves. A new study of the periodic signal from the quasar PG 1302-102 seems to confirm this interpretation by showing that it could naturally arise due to relativistic Doppler boosting.

Black-hole binaries are expected to be common in large elliptical galaxies, because they most likely form by the merger of spiral galaxies, each hosting a central SMBH. A way to find binary systems in quasars is to search for a period signal repeating over several years. This is quite challenging, owing to the erratic variability of these distant active galactic nuclei. Until recently, only one rather peculiar object, called OJ287, was clearly identified as a double black-hole system, with a smaller black hole plunging twice through the extended accretion disc of the primary black hole along its inclined, eccentric 12 year-long orbit.

In January, a team led by Matthew Graham, a computational astronomer at the California Institute of Technology, designed an algorithm to detect sinusoidal intensity variations from 247,000 quasars monitored by optical telescopes in Arizona and Australia. Of the 20 pairs of black-hole candidates discovered, they focused on the most compelling bright quasar – PG 1302-102. They showed that PG 1302-102 appeared to brighten by 14 per cent every five years, suggesting the pair was less than a tenth of a light-year apart.

Artist's conception of a pair of super-massive black holes, each surrounded by spiralling gas forming an accretion disc. (Image credit: P Marenfeld/NOAO/AURA/NSF.)

In a new study, also published in *Nature*, Daniel D'Orazio and his group at the Columbia University interpret the sinusoidal modulation as due to relativistic Doppler boosting. They find that the signal is consistent with a model where most of the optical emission comes from a smaller black hole orbiting a heavier one at nearly a tenth of the speed of light. At that speed – via the relativistic Doppler beaming effect – the smaller black hole would appear to slightly brighten as it approaches the Earth and fade as it moves away on its orbit. They note that hydrodynamical simulations do, indeed, suggest that the smaller black hole should be the brightest one.

According to this new interpretation, the observed quasi-sinusoidal signal in the optical emission of the quasar should also be seen in the ultraviolet (UV). Analysing archival UV observations collected by NASA's Hubble and GALEX space telescopes, D'Orazio and colleagues found the same period with a 2–3 times higher amplitude. The stronger signal corresponds precisely to the model expectations, by taking into account the difference of spectral slope measured from the optical to the UV.

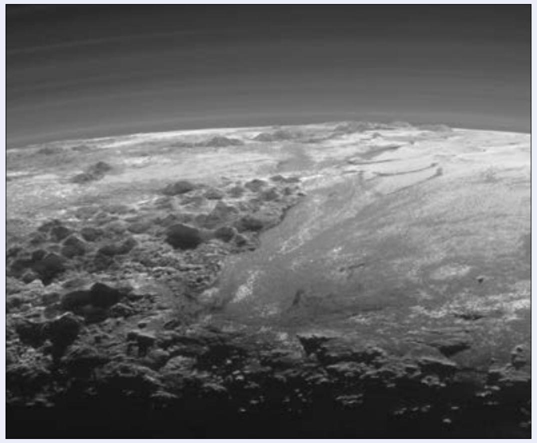
By estimating the combined and relative mass of the black holes in PG 1302-102, they narrow down the predicted time until the black holes coalesce to between 20,000 and 350,000 years from now, with a best estimate of 100,000 years – a very long time for humans but not in the life of stars and black holes. If confirmed by more observations in the years to come, this discovery and that of other binary black-hole candidates will improve the chances of witnessing a merger and the gravitational waves predicted, but not yet detected, by the theory of general relativity laid down by Einstein 100 years ago.

Weblinks

www.nature.com/nature/journal/v525/n7569/full/nature15262.html
www.nature.com/nature/journal/v518/n7537/full/nature14143.html
www.eurekalert.org/pub_releases/2015-09/cu-nsf090915.php
www.sciencedaily.com/releases/2015/09/150916162123.htm

Picture of the month

Just 15 minutes after its closest approach to Pluto on 14 July 2015, NASA's New Horizons spacecraft looked back towards the Sun and captured this amazing view of Pluto (Picture of the month, *CERN Courier* September 2015 p17). This near-sunset image offers a contrasting view between majestic mountains and frozen plains. The smooth expanse of the informally named Sputnik Planum (right) is flanked to the west (left) by rugged, icy mountains up to 3500 metres high, including the informally named Norgay Montes in the foreground and Hillary Montes on the skyline. The backlighting highlights more than a dozen layers of haze in Pluto's tenuous atmosphere, extending up to at least 100 km above the surface. Although the scene is only 380 km across, it displays a complex Earth-like view that scientists could not even dream to find on this remote dwarf planet. (Image credit: NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute.)



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pluto.jhuapl.edu/News-Center/News-Article.php?page=20150917

CERN Courier Archive: 1972

A LOOK BACK TO CERN COURIER VOL. 12, NOVEMBER 1972, COMPILED BY PEGGIE RIMMER

RESEARCH AND ITS DEVELOPMENTS

Applied research at CERN

In the words of its Convention, CERN exists "for nuclear research of a pure scientific and fundamental character and in research essentially related thereto".

The applied research undertaken at CERN has thus been directed to problems related to its physics programme. These often generate extreme needs in both scientific and technical skills, thus "frontier" research tends to promote advances in a variety of surrounding disciplines.

All knowledge emerging from the work of CERN is freely available for application elsewhere: by the direct use of a device or technique, by other uses of the knowledge unearthed, or from the increased expertise of industry working with CERN.

Perhaps we do not do enough to make known our applied-research activities.

● Compiled from texts on p359.

Multiwire and multipurpose

The multiwire proportional chamber (MWPC), in its present form, was born in 1968. The [single wire] proportional counter was around in the 1930s and its operation in the "proportional mode" was studied. Various types of multiwire chambers had been tried but a lack of understanding of the mechanisms at play limited their applications. In 1967 we constructed a small multiwire chamber using the knowledge we had from proportional counters, and the following were among the properties having the most consequences [on price, practicality and performance].

1. Considerable expenditure is needed on electronics, to collect and amplify a signal from each wire. A variety of gas mixtures were studied and a "magic gas" was found that gives a signal a hundred times higher than "classical" gases, easing the burden on the electronics. Techniques for grouping the circuits of several wires on the same wafer and specifying an integrated circuit for large-scale production should considerably reduce costs.

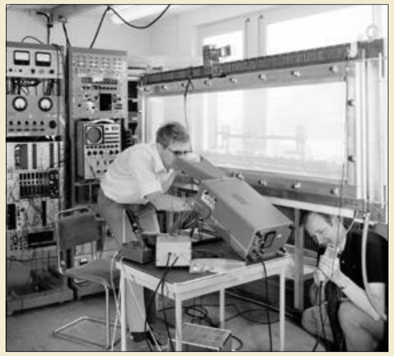
2. For some uses there were constructional difficulties in building large chambers. For example, a strong metal frame able to withstand the tension of hundreds of stretched wires would fill a significant proportion of the valuable aperture of the Split Field Magnet (SFM) at the Intersecting Storage Rings, so special honeycomb sandwiches of plastic foam are to be used. They have great strength and introduce much less matter.

3. Large MWPCs have been in action in the CERN–Heidelberg neutral kaon experiments for over a year, and the new technique allows several thousand events to be collected per Proton Synchrotron pulse [several orders of magnitude faster than spark chambers]. Another type of multiwire detector, the drift chamber, correlates the arrival time of a pulse at the wires with the position of the originating track. This correlation is so good that track coordinates can be measured with a precision of the order of 0.1 mm. Groups at Saclay and Heidelberg have put a lot of applied research into drift chambers, with a great role to play in the future.

A technique used to detect the coordinate parallel to the sensitive wire is not very interesting for high-energy physics, but gives the MWPC certain properties that the medical people consider essential to measure the distribution of radiation, X-rays or gamma rays, emitted by isotopes which have been fed into a human being. Active research on further uses is now being carried out in several hospitals.

Thus important applications for MWPCs have been found elsewhere. Serious difficulties have had to be overcome and perhaps are yet to be overcome. But, with the understanding which we have acquired of the phenomena underlying the behaviour of these chambers, we should be able to surmount them.

● Compiled from texts on pp362–364.



Far left: Testing a large chamber, as used in the CERN–Heidelberg experiments. Left: A prototype chamber for the aperture of the SFM. Special construction techniques achieve the evident lightness, but more importantly increase the useful detection volume. (Image credits: CERN.)

Compiler's Note

The 1972 article was written by the MWPC Nobel laureate himself, the late Georges Charpak: https://cds.cern.ch/record/1729418. It is an exemplary account of how frontier research is done and how it generates spin-off.

Is it widely known that particle detectors and accelerators used in nuclear medicine were developed for high-energy physics? And what about some familiar widgets? In 1973, Danish engineer Bent Stumpe was asked to replace the buttons, switches, etc, in CERN's Super Proton Synchrotron (SPS) control room by something simple (*CERN Courier* April 2010 p13). Within a matter of days, Bent had produced proposals for a touchscreen, a tracker ball and a programmable knob. Instantly deployed in the Lab, these were slower to catch on in industry, but nowadays no self(ie)-respecting geek would be seen without a touchscreen, Stumpe tracker-ball principles drive our mice, and programmable knobs are everywhere, such as a "Security programmable keyless-entry electronic digital door-lock knob", to quote the advertising blurb!

Perhaps CERN didn't do enough to make known some of its applied researchers.

Is the Standard Model about to crater?

The Standard Model is coming under more and more pressure from experiments. New results from the analysis of LHC's Run 1 data show effects that, if confirmed, would be the signature of new interactions at the TeV scale.

Kenneth Lane, Boston University.

There are now quite a few discrepancies, or "tensions", between laboratory experiments and the predictions of the Standard Model (SM) of particle physics. All of them are of the 2–3σ variety, exactly the kind that physicists learn not to take seriously early on. But many have shown up in a series of related measurements, and this is what has attracted physicists' attention.

In this article, I will concentrate on two sets of discrepancies, both associated with data taken at $\sqrt{s} = 7$ and 8 TeV in LHC's Run 1:

1. Using 3 fb^{-1} of data, LHCb has reported discrepancies with more or less precise SM predictions, all relating to the rare semileptonic transitions $b \to s l^+ l^-$, particularly with $l = \mu$. If real, they would imply the presence of new lepton non-universal (LNU) interactions at an energy scale $\Lambda_{LNU} \gtrsim 1$ TeV, well above the scale of electroweak symmetry breaking. Especially enticing, such effects would suggest lepton flavour violation (LFV) at rates much larger than expected in the Standard Model.

2. Using 20 fb^{-1} of data, ATLAS and CMS have reported 2–3σ excesses near 2 TeV in the invariant mass of dibosons VV = WW, WZ, ZZ and VH = WH, ZH, where H is the 125 GeV Higgs boson discovered in Run 1. To complicate matters, there is also a ~3σ excess near 2 TeV in a CMS search for a right-handed-coupling W_R decaying to l^+l^- jet jet (for $l = e$, but not μ), and a 2.3σ excess near $M_{jj} = 1.9$ TeV in dijet production. (Stop! I hear you say, and I can't blame you!)

If either set of discrepancies were to be confirmed in Run 2, the Standard Model would crack wide open, with new particles and their new interactions providing high-energy experimentalists and theorists with many years of exciting exploration and discovery. If both should be confirmed, Katy bar the door!

But first, I want to tip my hat to one of the longest-standing of all such SM discrepancies: the 2004 measurement of g–2 for the muon is 2.2–2.7σ higher than calculated. For a long time, this has been down-played by many, including me. After all, who pays attention to 2.5σ? (Answer: more than 1000 citations!) But now other things are showing up and, for LHCb, muons seem to be implicated. Maybe there's something there. We should know in a few years. The new muon g-2 experiment, E989 at Fermilab, is expected to have first results in 2017–2018.

$b \to s\mu^+\mu^-$ at LHCb

Features of LHCb's measurements of B-meson decays involving $b \to s l^+ l^-$ transitions hint consistently at a departure from the SM:

1. The measured ratio, R_K, of branching ratios of $B^+ \to K^+\mu^+\mu^-$ to $B^+ \to K^+e^+e^-$ is 25% lower than the SM prediction, a 2.6σ departure.

2. In an independent measurement, the branching ratio of $B^+ \to K^+\mu^+\mu^-$ is 30% lower than the SM prediction, a 2σ deficit. This suggests that the discrepancy is in muons, rather than electrons. LHCb's muon measurement is more robust than for electrons. However, all indications on the electron mode, including earlier results from Belle and BaBar, are that $B \to K^{(*)}e^+e^-$ is consistent with the SM.

3. The quantity P_5' in $B^0 \to K^{*0}\mu^+\mu^-$ angular distributions exhibits a 2.9σ discrepancy in each of two bins. The size of the theoretical error is being questioned, however.

4. CMS and LHCb jointly measured the branching ratio of $B_s \to \mu^+\mu^-$. The result is consistent with the SM prediction but, interestingly, its central value is also 25% lower (at 1σ).

The R_K and other measurements suggest lepton non-universality in $b \to s l^+ l^-$ transitions, and with a strength not very different from that of these rare SM processes. This prospect has inspired an avalanche of theoretical proposals of new LNU physics above the electroweak scale, all involving the exchange of multi-TeV particles such as leptoquarks or Z' bosons.

As a very exciting consequence, LNU interactions at high energy are, in general, accompanied by lepton flavour-violating interactions, unless the leptons involved are chosen to be mass eigenstates.

Physics beyond the SM and its Higgs boson has been expected for a long time, and for good theoretical reasons.

But, as we know from the mismatch between the gauge and mass eigenstates of quarks in the charged weak-interaction currents, there is no reason to make such a choice. Further, that choice makes no sense at Λ_{LNU}, far above the electroweak scale where those masses are generated. Therefore, if the LHCb anomalies were to be confirmed in Run 2, LFV ▷

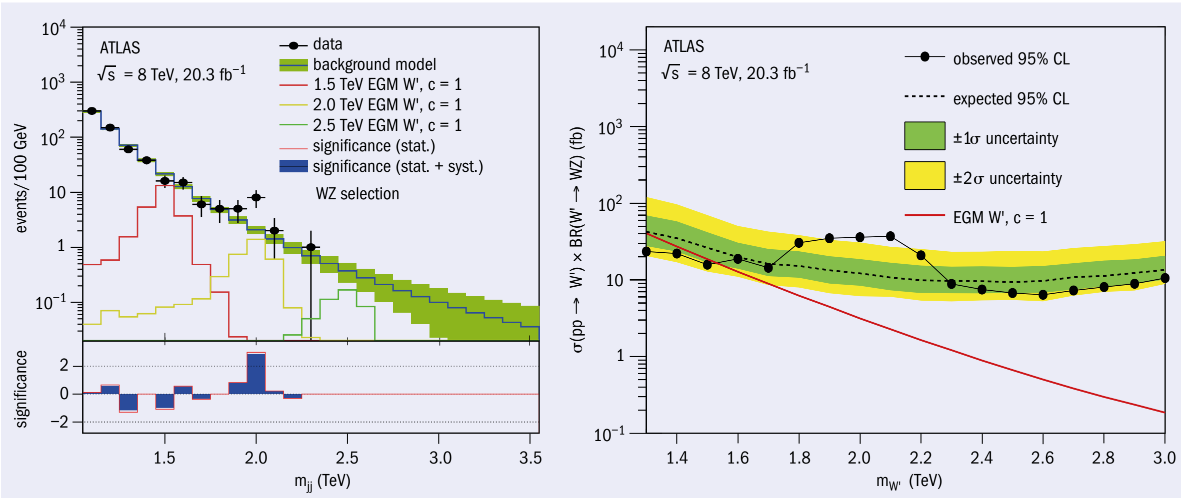


Fig. 1. Left: ATLAS non-leptonic M_{WZ} data. Right: ATLAS $\sigma \times B$ exclusion for $W' \to WZ$.

decays such as $B \to K^{(*)}\mu e/\mu\tau$ and $B_s \to \mu e/\mu\tau$ should occur at rates much larger than expected in the SM. (Note that LNU and LFV processes do occur in the SM but, being due to neutrino-mass differences, they are tiny.)

LHCb is searching for $b \to s\mu e$ and $s\mu\tau$ in Run 1 data, and will continue in Run 2 with much more data. The μe modes are easier targets experimentally than $\mu\tau$. However, the simplest hypothesis for LNU is that it occurs in the third-generation gauge eigenstates, e.g., a $\bar{b}'b'\bar{\tau}'\tau'$ interaction. Then, through the usual mass-matrix diagonalisation, the lighter generations get involved, with LFV processes suppressed by mixing matrix elements that are analogous to the familiar CKM elements. In this case, $b \to s\mu\tau$ likely will be the largest source of LFV in B-meson decays.

A final note: there are slight hints of the LFV decay $H \to \mu\tau$. CMS and ATLAS have reported small branching ratios that amount to 2.4σ and 1.2σ, respectively. These are tantalizing, and certainly will be clarified in Run 2.

Diboson excesses at ATLAS and CMS

I will limit this discussion to diboson, VV and VH, excesses near 2 TeV, even though the $W_R \to l^+l^-$ jet jet and dijet excesses are of similar size and should not be forgotten. ATLAS and CMS measured high-invariant-mass VV (V = W, Z) in non-leptonic events in which both highly boosted V decay into $\bar{q}q'$ (also called "fat" V-jets) and semi-leptonic events in which one V decays into $l^{\pm}\nu$ or l^+l^-. In the ATLAS non-leptonic data, a highly boosted V-jet is called a W (Z) if its mass M_V is within 13 GeV of 82.4 (92.8) GeV. In its semi-leptonic data, V = W or Z if 65 < MV < 105 GeV. In the non-leptonic events, ATLAS observed excesses in all three invariant-mass "pots", M_{WW}, M_{WZ} and M_{ZZ}, although there may be as much as 30% overlap between neighbouring pots. Each of the three excesses amount to 5–10 events. The largest excess is in M_{WZ}. It is centred at 2 TeV, with a 3.4σ local, 2.5σ global significance. ATLAS's WZ data and exclusion plot are in figure 1. The WZ excess has been estimated to correspond to a cross-section times branching ratio of about 10 fb. ATLAS observed no excesses near 2 TeV in its semileptonic data. Given the low statistics of the non-leptonic excesses, this is not yet an inconsistency.

In its non-leptonic data, CMS defined a V-jet to be a W or Z candidate if its mass is between 70 and 100 GeV. The exclusion plot for this data shows a ~1.5σ excess over the expected limit near M_{VV} = 1.9 TeV. In the semi-leptonic data, the V-jet is called a W if $65 < M_V < 105$ GeV or a Z if $70 < M_V < 110$ GeV – a quite substantial overlap. There is a 2σ excess over the expected background near 1.8 TeV in the l^+l^- V-jet but less than 1σ in the $l^{\pm}\nu$ V-jet. When the semi-leptonic and non-leptonic data are combined, there is still a 1.5–2σ excess near 1.8 TeV. The CMS exclusion plots are in figure 2.

ATLAS and CMS also searched for resonant structure in VH production. ATLAS looked in the channels $l\nu/l^+l^-/\nu\nu + \bar{b}b$ with one and two b-tags. Exclusion plots up to 1.9 TeV show no deviation greater that 1σ from the expected background. CMS looked in non-leptonic and semi-leptonic channels. The observed non-leptonic exclusion curves look like a sine wave of amplitude 1σ on the expected falling background with, as luck would have it, a maximum at 1.7 TeV and a minimum at 2 TeV. On the other hand, a search for $WH \to l\nu\bar{b}b$ has a 2σ excess centred at 1.9 TeV in the electron, but not the muon, data.

Many will look at these 2–3σ effects and say they are to be expected when there is so much data and so many analyses; indeed, something would be wrong if there were not. Others, including many theorists, will point to the number, proximity and variety of these fluctuations in both experiments at about the same mass, and say something is going on here. After all, physics beyond the SM and its Higgs boson has been expected for a long time and for good theoretical reasons.

It is no surprise, then, that a deluge of more than 60 papers has appeared since June, vying to explain the 2 TeV bumps. The two most popular explanations are (1) a new weakly coupled W', Z' triplet that mixes slightly with the familiar W, Z, and (2) a triplet of ρ-like vector bosons heralding new strong interactions associated with H being a composite Higgs boson. A typical motivation for the W' scenario is the restoration of right–left symmetry in the weak interactions. The

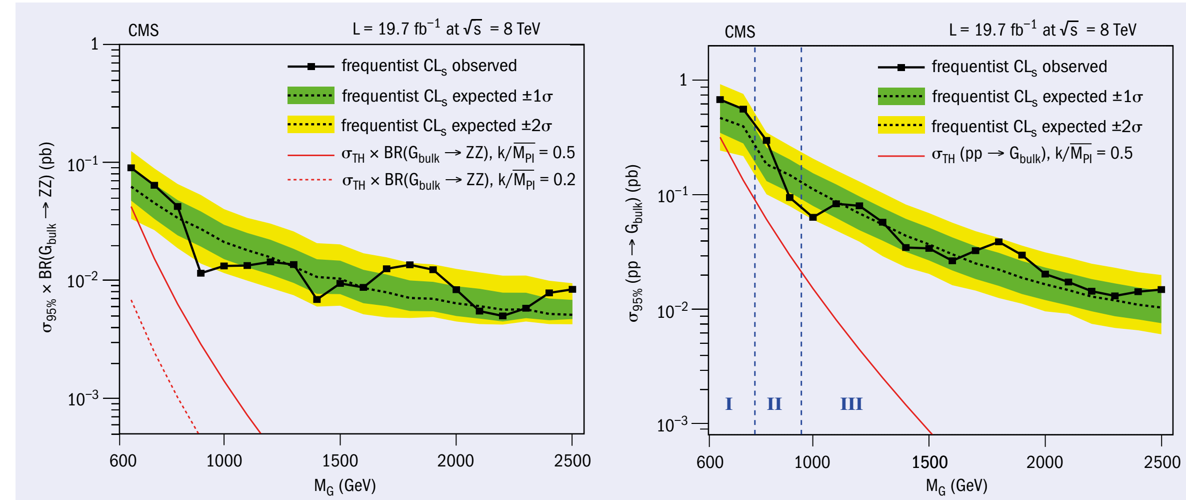


Fig. 2. Left: CMS semi-leptonic $X \to ZZ$ exclusion. Right: CMS semi-leptonic + non-leptonic $X \to ZZ$ exclusion.

composite Higgs is a favourite of "naturalness theorists" trying to understand why H is so light. The new interactions of both scenarios have an "isospin" SU(2) symmetry. The new isotriplets X are produced at the femtobarn level, mainly in the Drell–Yan process of $\bar{q}q$ annihilation. Their main decay modes are $X^{\pm} \to W_L^{\pm} Z_L$ and $X^0 \to W_L^+ W_L^-$, where V_L is a longitudinally polarised weak boson. Generally, the W', Z' and the ρ (or its parity partner, an a_1-like triplet) can also decay to W_L, Z_L plus H itself. It follows that the diboson excess attributed to ZZ would really have to be WZ and, possibly, WW. The W, Z-polarisation and the absence of real ZZ are important early tests of these models. (A possibility not considered in the composite Higgs papers, is the production of an f_0-like I = 0 scalar, also at 2 TeV, which decays to $W_L^+W_L^-$ and $Z_L Z_L$.)

Although the most likely explanation of the 2 TeV bumps may well be statistics, we should have confirmation soon. The resonant cross-sections are five or more times larger at 13 TeV than at 8 TeV. Thus, the expected LHC running this year and next will produce as much or more diboson data as all of Run 1.

What if both lepton flavour violation and the VV and VH bumps were to be discovered in Run 2? Both would suggest new interactions at or above a few TeV. Surely they would have to be related, but how? New weak interactions could be flavour non-universal (but, then, not right–left symmetric). New strong interactions of Higgs compositeness could easily be flavour non-universal. The possibilities seem endless. So do the prospects for discovery. Stay tuned!

● For the B-meson anomalies, the experimental papers are arxiv.org/abs/1406.6482, arxiv.org/abs/1403.8044, arxiv.org/abs/1505.04160 and arxiv.org/abs/1411.4413. For the diboson excesses near 2 TeV, the details of the V-jet construction are in arxiv.org/abs/1506.00962, arxiv.org/abs/1503.04677 and arxiv.org/abs/1409.6190 for ATLAS, and arxiv.org/abs/1405.1994 and arxiv.org/abs/1405.3447 for CMS.

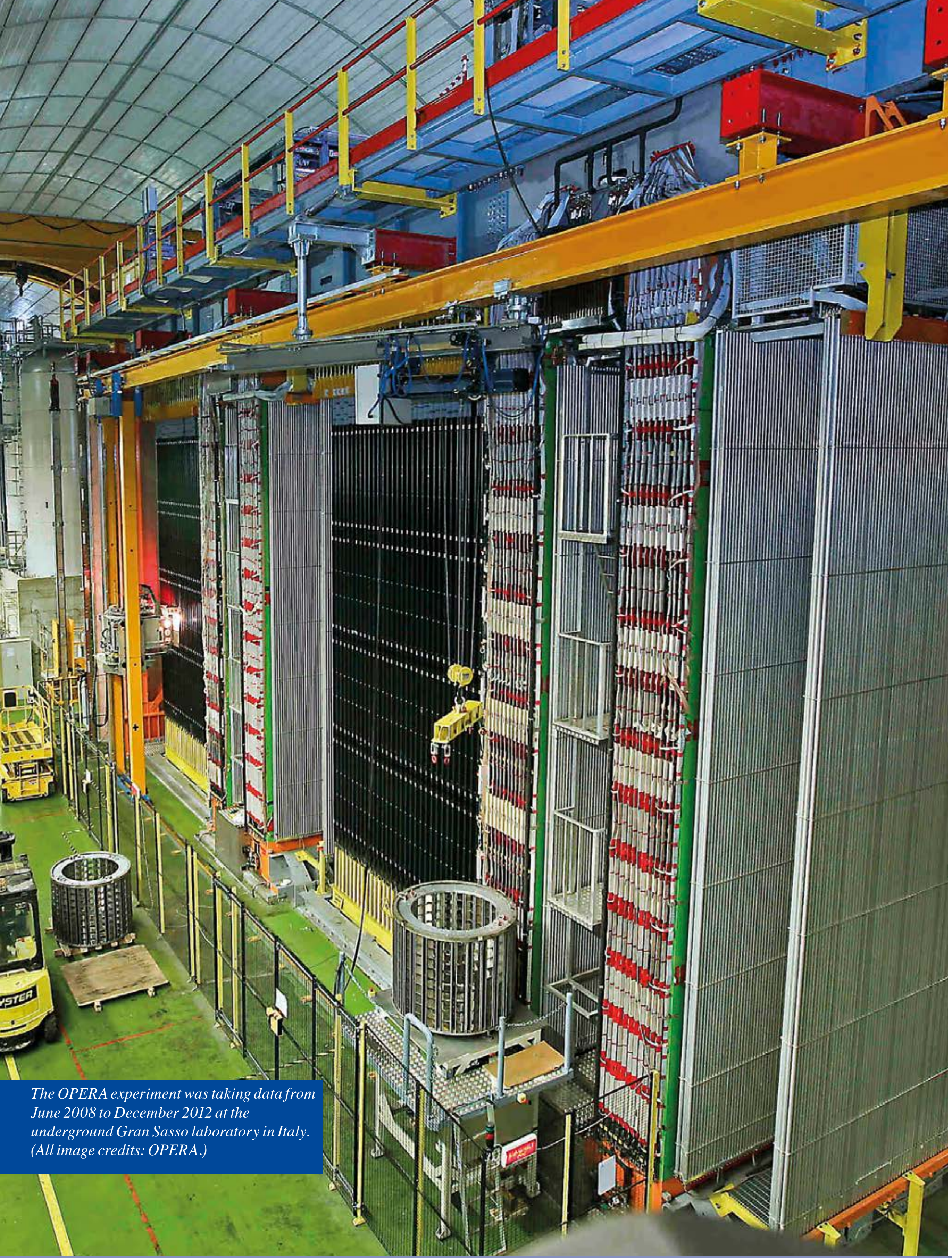
Résumé

Le Modèle standard bientôt dépassé ?

Le Modèle standard de la physique des particules semble de plus en plus près d'être remis en cause par les expériences. C'est particulièrement flagrant dans certains résultats récents d'analyses de données de la première période d'exploitation du LHC : la violation apparente de l'universalité des leptons dans certaines désintégrations semileptoniques de mésons B d'après les mesures de LHCb, et l'observation par ATLAS comme par CMS d'excédents aux alentours de 2 TeV dans la masse invariante de paires de bosons faibles et de paires constituées d'un boson faible plus du boson de Higgs récemment découvert. Si l'un ou l'autre de ces effets est confirmé au début de la deuxième période d'exploitation, cela signifie que de nouvelles interactions auront été découvertes et que le Modèle standard aura finalement été dépassé.

● Among the "tensions" not discussed in this article is also the $B \to D^* \tau\nu$ decay, illustrated on the cover of this issue.

What's next for OPERA's emulsion-detection technology?



The OPERA experiment was taking data from June 2008 to December 2012 at the underground Gran Sasso laboratory in Italy. (All image credits: OPERA.)

While working on the analysis of their data, the collaboration is also looking into possible developments of their emulsion-detection technology, to be implemented in future experiments.

Luciano Maiani, Università La Sapienza and INFN Roma 1, and **Giovanni De Lellis**, Università Federico II and INFN Napoli.

Developed in the late 1990s, the OPERA detector design was based on a hybrid technology, using both real-time detectors and nuclear emulsions. The construction of the detector at the Gran Sasso underground laboratory in Italy started in 2003 and was completed in 2007 – a giant detector of around 4000 tonnes, with 2000 m^3 volume and nine million photographic films, arranged in around 150,000 target units, the so-called bricks. The emulsion films in the bricks act as tracking devices with micrometric accuracy, and are interleaved with lead plates acting as neutrino targets. The longitudinal size of a brick is around 10 radiation lengths, allowing for the detection of electron showers and the momentum measurement through the detection of multiple Coulomb scattering. The experiment took data for five years, from June 2008 until December 2012, integrating 1.8×10^{20} protons on target.

The aim of the experiment was to perform the direct observation of the transition from muon to tau neutrinos in the neutrino beam from CERN. The distance from CERN to Gran Sasso and the SPS beam energy were just appropriate for tau-neutrino detection. In 1999, intense discussions took place between CERN management and Council delegations about the opportunity of building the CERN Neutrino to Gran Sasso (CNGS) beam facility and the way to fund it. The Italian National Institute for Nuclear Physics (INFN) was far-sighted in offering a sizable contribution. Many delegations supported the idea, and the CNGS beam was approved in December 1999. Commissioning was performed in 2006, when OPERA (at that time not fully equipped yet) detected the first muon-neutrino interactions.

With the CNGS programme, CERN was joining the global experimental effort to observe and study neutrino oscillations. The first experimental hints of neutrino oscillations were gathered from solar neutrinos in the 1970s. According to theory, neutrino oscillations originate from the fact that mass and weak-interaction eigenstates do not coincide and that neutrino masses are non-degenerate. Neutrino mixing and oscillations were introduced by Pontecorvo and by the Sakata group, assuming the existence of two sorts (flavours) of neutrinos. Neutrino oscillations with three flavours including CP and CPT violation were discussed by Cabibbo and by Bilenky and Pontecorvo, after the discovery of the tau lepton in 1975. The mixing of the three flavours of neutrinos can be described by the 3 × 3 Pontecorvo–Maki–Nakagawa–Sakata matrix with three angles – that have since been measured – and a CP-violating phase, which remains unknown at present. Two additional parameters (mass-squared differences) are needed to describe the oscillation probabilities.

Several experiments on solar, atmospheric, reactor and accelerator neutrinos have contributed to the understanding of neutrino oscillations. In the atmospheric sector, the strong deficit of muon neutrinos reported by the Super-Kamiokande experiment in 1998 was the first compelling observation of neutrino oscillations. Given that the deficit of muon neutrinos was not accompanied by an increase of electron neutrinos, the result was interpreted in terms of $\nu_\mu \to \nu_\tau$ oscillations, although in 1998 the tau neutrino had not yet been observed. The first direct evidence for tau neutrinos was announced by Fermilab's DONuT experiment in 2000, with four reported events. In 2008, the DONuT collaboration presented its final results, reporting nine observed events and an expected background of 1.5. The Super-Kamiokande result was later confirmed by the K2K and MINOS experiments with terrestrial beams. However, for an unambiguous confirmation of three-flavour neutrino oscillations, the appearance of tau neutrinos in $\nu_\mu \to \nu_\tau$ oscillations was required.

OPERA comes into play

OPERA reported the observation of the first tau-neutrino candidate in 2010. The tau neutrino was detected by the production and decay of a τ^- in one of the lead targets, where $\tau^- \to \rho^- \nu_\tau$. A second candidate, in the $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ channel, was found in 2012, followed in 2013 by a candidate in the fully leptonic $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$ decay. A fourth event was found in 2014 in the $\tau^- \to h^- \nu_\tau$ channel (where h^- is a pion or a kaon), and a fifth one was reported a few months ago in the same channel. Given the extremely low expected background of 0.25±0.05 events, the direct transition from muon to tau neutrinos has now been measured with the 5σ statistical precision conventionally required to firmly establish its observation, confirming the oscillation mechanism.

The extremely accurate detection technique provided by OPERA relies on the micrometric resolution of its nuclear emulsions, which are capable of resolving the neutrino-interaction point and the vertex-decay location of the tau lepton, a few hundred micrometres ▷

Experiments' legacy

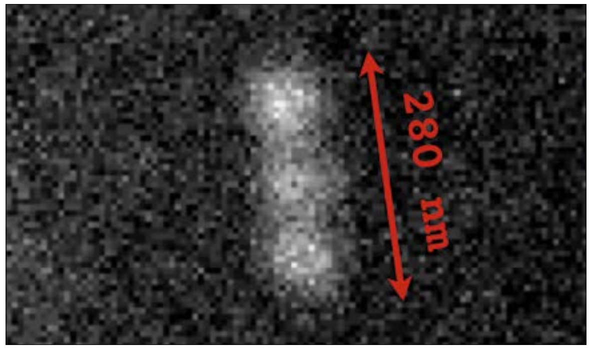
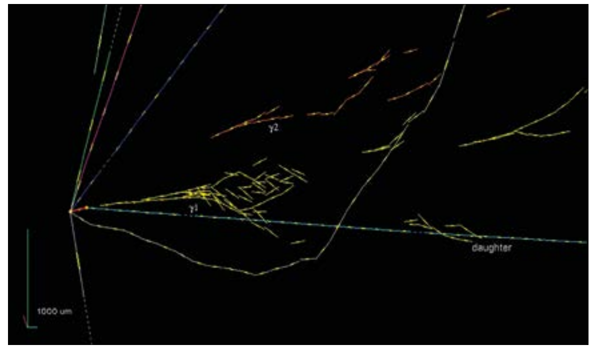


Image from the new-generation nuclear emulsions developed for the dark-matter search.



The first tau-neutrino interaction observed by OPERA in its nuclear emulsions.

away. The tau-neutrino identification is first topological, then kinematical cuts are applied to suppress the residual background, thus giving a signal-to-noise ratio larger than 10. In general, the detection of tau neutrinos is extremely difficult, due to two conflicting requirements: a huge, massive detector and the micrometric accuracy. The concept of the OPERA detector was developed in the late 1990s with relevant contributions from Nagoya – the emulsion group led by Kimio Niwa – and from Naples, under the leadership of Paolo Strolin, who led the initial phase of the project.

The future of nuclear emulsions

Three years after the end of the CNGS programme, the OPERA collaboration – about 150 physicists from 26 research institutions in 11 countries – is finalising the analysis of the collected data. After the discovery of the appearance of tau neutrinos from the oscillation of muon neutrinos, the collaboration now plans to further exploit the capability of the emulsion detector to observe all of the three neutrino flavours at once. This unique feature will allow OPERA to constrain the oscillation matrix by measuring tau and electron appearance together with muon-neutrino disappearance.

An extensive development of fully automated optical microscopes for the scanning of nuclear-emulsion films was carried out along with the preparation and running of the OPERA experiment. These achievements pave the way for using the emulsion technologies in forthcoming experiments, including SHiP (Search for Hidden Particles), a new facility that was recently proposed to CERN. If approved, SHiP will not only search for hidden particles in the GeV mass range, but also study tau-neutrino physics and perform the first direct observation of tau antineutrinos. The tau-neutrino detector of the SHiP apparatus is designed to use nuclear emulsions similar to those used by OPERA. The detector will be able to identify all three neutrino flavours, while the study of muon-neutrino scattering with large statistics is expected to provide additional insights into the strange-quark content of the proton, through the measurement of neutrino-induced charmed hadron production.

Currently, the R&D work on emulsions continues mainly in Italy and Japan. Teams at Nagoya University have successfully produced emulsions with AgBr crystals of about 40 nm diameter – one order of magnitude smaller than those used in OPERA. In parallel, significant developments of fully automated optical-scanning systems, carried out in Italy and Japan with innovative analysis technologies, have overcome the intrinsic optical limit and achieved the unprecedented position resolution of 10 nm. Both achievements make it possible to use emulsions for the detection of sub-micrometric tracks, such as those left by nuclear recoils induced by dark-matter particles (Weakly Interacting Massive Particles, WIMPs). This paves the way for the first large-scale dark-matter experiment with directional information. The NEWS experiment (Nuclear Emulsions for WIMP Search) plans to carry out this search at the Gran Sasso underground laboratory.

Thanks to their extreme accuracy and capability of identifying particles, nuclear emulsions are also successfully employed in fields beyond particle physics. Exploiting the cosmic-ray muon radiography technique, sandwiches of OPERA-like emulsion films and passive materials were used to image the shallow-density structure beneath the Asama Volcano in Japan and, more recently, to image the crater structure of the Stromboli volcano in Italy. Detectors based on nuclear emulsions are also used in hadron therapy to characterize the carbon-ion beams and their secondary interactions in human tissues. The high detection accuracy provided by emulsions allows experts to better understand the secondary effects of radiation, and to monitor the released dose with the aim of optimizing the planning of medical treatments.

● For more information, visit http://operaweb.lngs.infn.it/.

Résumé

La détection par émulsion à OPERA : perspectives

Mis au point à la fin des années 1990, le détecteur OPERA a été conçu à partir d'une technologie hybride, avec l'utilisation à la fois de détecteurs en temps réel et d'émulsions nucléaires. Aujourd'hui, tout en poursuivant l'analyse des données, la collaboration travaille sur les développements possibles de la technologie de détection par émulsion, qui sera mise en œuvre dans les expériences futures. De plus, grâce à leur précision extrême et à leur capacité d'identifier les particules, les émulsions nucléaires sont utilisées dans d'autres domaines que la physique des particules, notamment l'hadronthérapie, ou encore les études géophysiques, où elles permettent d'analyser les structures présentes sous les volcans.

The 240 m-long building of the old Canfranc Estación railway station. The historic landmark is only a few kilometres away from the entrance to the Canfranc Underground Laboratory. (All image credits: LSC.)

The LSC welcomes new experiments

From underground physics to geology and biology, the research programme carried out at the Canfranc Underground Laboratory involves a rich variety of experiments.

Aldo Ianni, director of the LSC.

The Canfranc Underground Laboratory (LSC) in Spain is one of four European deep-underground laboratories, together with Gran Sasso (Italy), Modane (France) and Boulby (UK). The laboratory is located at Canfranc Estación, a small town in the Spanish Pyrenees situated about 1100 m above sea level. Canfranc is known for the railway tunnel that was inaugurated in 1928 to connect Spain and France. The huge station – 240 m long – was built on the Spanish side, and still stands as proof of the history of the place, although the railway operation was stopped in 1970.

In 1985, Angel Morales and his collaborators from the University of Zaragoza started to use the abandoned underground space to carry out astroparticle-physics experiments. In the beginning, the group used two service cavities, currently called LAB780. In 1994, during the excavation of the 8 km-long road tunnel (Somport tunnel), an experimental hall of 118 m^2 was built 2520 m away from the Spanish entrance. This hall, called LAB2500, was used to install a number of experiments carried out by several international collaborations. In 2006, two additional larger halls – hall A and hall B, collectively called LAB2400 – were completed and ready for use. The LSC was born.

Today, some 8400 m^3 are available to experimental installations at Canfranc in the main underground site (LAB2400), and a total volume of about 10,000 m^3 on a surface area of 1600 m^2 is available among the different underground structures. LAB2400 has about 850 m of rock overburden with a residual cosmic muon flux of about $4\times10^{-3}\,m^{-2}\,s^{-1}$. The radiogenic neutron background (< 10 MeV) and the gamma-ray flux from natural radioactivity in the rock environment at the LSC are determined to be of the order of 3.5×10^{-6} n/(cm^2 s) and 2γ/(cm^2 s), respectively. The neutron flux is about 30 times less intense than on the surface. The radon level underground is kept in the order of 50–80 Bq/m^3 by a ventilation system with fresh-air input of about 19,600 m^3/h and 6300 m^3/h for hall A and B, ▷

One section of the 70 m laser strainmeter installed at the LSC to study local and global geodynamic events.

respectively. To reduce the natural levels of radioactivity, a new radon filtering system and a radon detector with a sensitivity of mBq/m^3 will be installed in hall A in 2016, to be used by the experiments.

The underground infrastructure also includes a clean room to support detector assembly and to maintain the high level of cleanliness required for the most important components. A low-background screening facility, equipped with seven high-purity germanium γ-spectrometers, is available to experiments that need to select components with low radioactivity for their detectors. The screening facility has recently been used by the SuperKGd collaboration to measure the radiopurity of gadolinium salts for the Super-Kamiokande gadolinium project.

A network of 18 optical fibres, each equipped with humidity and temperature sensors, is installed in the main halls to monitor the rock stability. The sensitivity of the measurement is at the micrometer level; so far, across a timescale of four years, changes of 0.02% have been measured over 10 m scale lengths.

The underground infrastructure is complemented by a modern 1800 m^2 building on the surface, which houses offices, a chemistry and an electronics laboratory, a workshop and a warehouse. Currently, some 280 scientists from around the world use the laboratory's facilities to carry out their research.

The scientific programme at the LSC focuses on searches for dark matter and neutrinoless double beta decay, but it also includes experiments on geodynamics and on life in extreme environments.

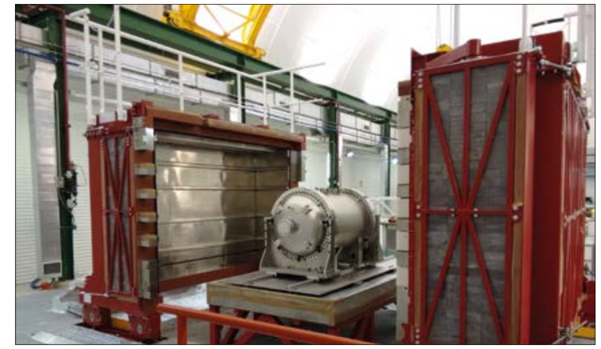
Neutrinoless double beta decay

Unlike the two-neutrino mode observed in a number of nuclear decays ($\beta\beta2\nu$, e.g. ${}^{136}Xe \rightarrow {}^{136}Ba + 2e^- + 2\bar{\nu}_e$), the neutrinoless mode of double beta decay ($\beta\beta0\nu$, e.g. ${}^{136}Xe \rightarrow {}^{136}Ba + 2e^-$) is as yet unobserved. The experimental signature of a neutrinoless double beta decay would be two electrons with total energy equal to the energy released in the nuclear transition. Observing this phenomenon would demonstrate that the neutrino is its own anti-particle, and is one of the main challenges in physics research carried out in underground laboratories. The NEXT experiment at the LSC aims to search for those experimental signatures in a high-pressure time projection chamber (TPC), using xenon enriched in ${}^{136}Xe$. The NEXT TPC is designed with a plane of photomultipliers on the cathode and a plane of silicon photomultipliers behind the anode. This set-up allows the collaboration to determine the energy and the topology of the event, respectively. In this way, background from natural radioactivity and from the environment can be accurately rejected. In its final configuration, NEXT will use 100 kg of ${}^{136}Xe$ and 15 bar pressure. A demonstrator of the TPC with 10 kg of Xe, named NEW, is currently being commissioned at the LSC.

The Canfranc Laboratory also hosts R&D programmes in support of projects that will be carried out in other laboratories. An example is BiPo, a high-sensitivity facility that measures the radioactivity on thin foils for planar detectors. Currently, BiPo is performing measurements for the SuperNEMO project proposed at the Modane laboratory. SuperNEMO aims to make use of 100 kg of ${}^{82}Se$ in thin foils to search for $\beta\beta0\nu$ signatures. These foils must have very low contamination from other radioactive elements. In particular, the contamination must be less than 10 μBq/kg for ${}^{214}Bi$ from the ${}^{238}U$ decay chain, and less than 2 μBq/kg for ${}^{208}Tl$ from the ${}^{232}Th$ decay chain. These levels of radioactivity are too small to be measured with standard instruments. The BiPo experiment provides a technical solution to perform this very accurate measurement using a thin ${}^{82}Se$ foil (40 mg/cm^2) that is inserted between two detection modules equipped with scintillators and photomultipliers to tag ${}^{214}Bi$ and ${}^{208}Tl$.

Dark matter

The direct detection of dark matter is another typical research activity of underground laboratories. At the LSC, two projects are in operation for this purpose: ANAIS and ArDM. In its final configuration, ANAIS will be an array of 20 ultrapure NaI(Tl) crystals aiming at investigating the annual modulation signature of dark-matter particles coming from the galactic halo. Each 12.5 kg crystal is put inside a high-purity electroformed copper shielding made at the LSC chemistry laboratory. Roman lead of 10 cm thickness, plus other lead structures totalling 20 cm thickness, are installed around the crystals, together with an active muon veto and passive neutron shielding. In 2016, the ANAIS detector will be in operation with a total of 112 kg high-purity NaI(Tl) crystals.



The vessel of the demonstrator of the NEXT experiment is currently being commissioned at the LSC. The lead walls shield the stainless-steel vessel from residual radioactivity.

Experimental hall A at the LSC. Experiments searching for dark matter and neutrinoless double beta decay are installed here.

A different experimental approach is adopted by the ArDM detector. ArDM makes use of two tonnes of liquid argon to search for WIMP interactions in a two-phase TPC. The TPC is viewed by two arrays of 12 PMTs and can operate in single phase (liquid only) or double phase (liquid and gas). The single-phase operation mode was successfully tested up to summer 2015, and the collaboration will be starting the two-phase mode by the end of 2015.

Nuclear astrophysics

In recent decades, the scientific community has shown growing interest in measuring cross-sections of nuclear interactions taking place in stars. At the energy of interest (that is, the average energy of particles at the centre of the stars), the expected interaction rates are very small. The signal is so small that the measurement can only be performed in underground laboratories where the levels of background are reduced. For this reason, a project has been proposed at the LSC: the Canfranc Underground Nuclear Astrophysics (CUNA) facility. CUNA would require a new experimental hall to host a linear accelerator and the detectors. A feasibility study has been carried out and further developments are expected in the coming years.

Geodynamics

The geodynamic facility at the LSC aims to study local and global geodynamic events. The installation consists of a broadband seismometer, an accelerometer and two laser strainmeters underground, and two GPS stations on the surface in the surroundings of the underground laboratory. This facility allows seismic events to be studied over a wide spectrum, from seismic waves to tectonic deformations. The laser interferometer consists of two orthogonal 70 m-long strainmeters. Non-linear shallow water tides have been observed with this set-up and compared with predictions. This was possible because of the excellent signal-to-noise ratio for strain data at the LSC.

Life in extreme environments

In the 1990s, it became evident that life on Earth extends into the deep subsurface and extreme environments. Underground facilities can be an ideal laboratory for scientists specialising in astrobiology, environmental microbiology or other similar disciplines. The GOLLUM project proposed at the LSC aims to study micro-organisms inhabiting rocks underground. The project plans to sample the rock throughout the length of the railway tunnel and characterize microbial communities living at different depths (metagenomics) by DNA extraction.

Currently operating mainly in the field of dark matter and the search for rare decays, the LSC has the potential to grow as a multidisciplinary underground research infrastructure. Its large infrastructure equipped with specialized facilities allows the laboratory to host a variety of experimental projects. For example, the space previously used by the ROSEBUD experiment is now available to collaborations active in the field of direct dark-matter searches or exotic phenomena using scintillating bolometers or low-temperature detectors. A hut with exceptionally low acoustic and vibrational background, equipped with a 3 × 3 × 4.8 m^3 Faraday cage, is available in hall B. This is a unique piece of equipment in an underground facility that, among other things, could be used to characterize new detectors for low-mass dark-matter particles. Moreover, some 100 m^2 are currently unused in hall A. New ideas and proposals are welcome, and will be evaluated by the LSC International Scientific Committee.

- For further details about the LSC, visit www.lsc-canfranc.es.

Résumé

Le Laboratoire souterrain de Canfranc : astroparticules, et plus si affinités

Le Laboratoire souterrain de Canfranc (LSC), en Espagne, est l'un des quatre laboratoires souterrains en Europe, avec ceux du Gran Sasso (Italie), de Modane (France) et de Boulby (Royaume-Uni). Situé à Canfranc Estación, petite ville des Pyrénées espagnoles, à environ 1 100 m d'altitude, le laboratoire, actuellement consacré essentiellement à la physique des astroparticules et à la recherche des désintégrations rares, a le potentiel d'une future infrastructure de recherche souterraine multidisciplinaire. Les idées et propositions nouvelles sont les bienvenues ; elles seront évaluées par le Comité scientifique du LSC.

Faces & Places

Conferences

TAUP 2015 gives updated overview on astroparticle and underground physics

Participants gather for a group photograph at the TAUP 2015 conference, held in Torino (Italy). (Image credit: TAUP 2015.)

Around 500 physicists, astrophysicists and cosmologists from 38 countries convened in Torino to discuss current developments in astroparticle physics and particle cosmology. The 14th edition of the International Conference on Topics in Astroparticle and Underground Physics (TAUP 2015) was held in Torino from 7 to 11 September, and was organised by the University of Torino, the National Institute for Nuclear Physics (INFN), the National Institute for Astrophysics (INAF), the Italian Space Agency (ASI), the Gran Sasso National Laboratory (LNGS), the Torino Science Academy and the Inter-university Centre for Space Physics (CIFS).

The scientific focus of the TAUP conference is theoretical and experimental progress on dark matter, neutrino physics, high-energy astrophysics and cosmic rays, cosmology and gravitational waves. The biennial TAUP conference series started in 1989 in L'Aquila. Since then, it has grown to be the major event in astroparticle and underground physics. This latest edition saw unprecedented participation, and full days of lively discussions and exchanges on all current key subjects of particle astrophysics and cosmology. As is traditional for TAUP, the conference was organised as plenary review talks in the mornings, and workshop sessions held in parallel in the afternoons. A dedicated poster session completed the programme.

The plenary programme – 32 talks in total – opened with three reviews on the current status of cosmological observations and its connections to particle physics. It then moved to cover high-energy astrophysics, with reports on γ rays and cosmic-ray observations, both from Earth and space. High-energy neutrinos have been a hot topic: a comprehensive theoretical exploration of high-energy messengers and their sources placed the observational results in context.

Major players

Dark matter was discussed, both in the high- and low-energy mass windows, from axions to WIMPs, with reports on the current theoretical understanding and experimental searches for new physics. After a detailed and informative overview of dark-matter distribution on small scales, a critical element for particle dark-matter astrophysical signals, the whole spectrum of indirect- and direct-detection strategies was covered extensively. Highlights included new avenues like directionality in direct detection, and anisotropies and cross-correlations in indirect-detection searches.

Neutrino physics was another major player: the theoretical landscape of neutrino physics, including sterile neutrinos, was the background for reports on the whole experimental programme in the field: measurement of the absolute neutrino masses, reactor neutrinos, short- and long-baseline experiments, neutrinoless double-beta decay, low-energy neutrinos, solar, geo and supernova neutrinos.

The gravitational-wave session reported on the kick-off of the second phase of advanced interferometers, happening this year, such as the start of the LISA pathfinder mission. A talk on multimessenger astronomy provided a link to the high-energy and neutrino sessions.

The plenary programme was further enriched by the well-attended workshop sessions, six each afternoon, and the poster session, where the topics covered in the plenary sessions were explored in greater depth with more focussed presentations. With more than 340 contributions, the sessions offered a complete and exhaustive overview of the experimental results and their theoretical and phenomenological interpretations.

TAUP 2015 also paid special attention to outreach and science communication. The conference programme included a dedicated parallel session, which was well-attended both by specialists and scientists. Three outreach events, aimed at the general public, were organised in the city. One of these was a fulldome planetarium show on dark matter and particle physics, set up in collaboration with the CERN Media Lab and LBNL, and held at the Torino Planetarium. The event was very much appreciated by the general public.

● For further details, visit taup2015.to.infn.it.

Dallas welcomes the DIS2015 International Workshop

Conference participants on the steps of SMU (top), and enjoying the social events (above left), which included the conference banquet at the Perot Museum of Nature and Science (above right). (Image credits: DIS2015.)

This spring, the 23rd International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS2015) took place at the Southern Methodist University (SMU) in Dallas, Texas. The workshop was held from 27 April to 1 May, and included some 250 participants representing 30 countries, presenting more than 200 talks on a multitude of subjects. The programme reported on current developments in DIS and QCD, as well as updates on the latest results from the LHC, HERA, Tevatron, Jefferson Lab, RHIC and fixed-target experiments. It also covered related theoretical topics and future experimental opportunities.

The workshop began with a full day of plenary reports on recent progress from both the experiment and theory frontiers; these excellent overview presentations stimulated extensive discussion and generated interest for the upcoming parallel talks. This was followed by two and a half days of parallel talks, organised around seven themes: structure functions and parton densities; small-x, diffraction and vector mesons; electroweak physics and beyond the Standard Model; QCD and hadronic final states; heavy flavours; spin physics; and future experiments.

Work on the structure of the proton has seen tremendous advances recently. The final HERAPDF2.0 results were presented, as well as updates from the individual groups working on parton-distribution functions (PDFs). These discussions were timely because the PDF improvements will help with analysis of the LHC Run 2.

There were also extensive updates from the LHC on the properties of the Higgs boson, as well as prospects for searching for new Higgs-like objects including SUSY, extra gauge bosons (W′, Z′) and other exotica. Precision measurements from both RHIC and LHC experiments can also place constraints on new physics signatures such as "dark photons".

On the heavy-flavours frontier, new improvements on theoretical calculations matched with new experimental measurements from RHIC and the LHC were seen. Heavy-flavour production is an incisive tool, which can probe many features of QCD; however, the heavy-quark mass introduces an additional scale, which complicates the theoretical calculations. Nevertheless, new techniques, clever ideas and hard work have enabled progress to be made in this area.

The spin-physics session had extensive discussions on HERMES and COMPASS data, as well as measurements from RHIC and Jefferson Lab experiments. This was complemented on the theoretical side by advances in generalized PDFs, which can reconstruct the proton structure in 3D.

The future of DIS

In the areas of small-x, diffraction and vector mesons, a wide range of interesting topics were presented, including parton saturation and shadowing, non-linear evolution, tests of factorisation, and rapidity-gap physics for both protons and nuclei.

The future landscape of DIS was also discussed, including the JLab 12 GeV upgrade, the Deep Underground Neutrino Experiment (DUNE) at the Long-Baseline Neutrino Facility (LBNF), the Electron-Ion-Collider (EIC) and the LHeC. In combination, these projects will vastly extend the reach of DIS to study matter from the lowest to highest energies and densities.

The workshop programme made room for several social and outreach events, including a public lecture entitled "If the universe is the answer, what is the question?" This event featured four physicists from the workshop discussing critically important unanswered physics questions that upcoming experiments might help to resolve. The presentations were stimulating and thought provoking, and gave the local audience a non-technical glimpse into issues discussed at the workshop.

The social highlight of the meeting was the "Night at the Science Museum" conference banquet, which was held at Dallas's new Perot Museum of Nature and Science. The museum blends art, technology and science with renowned interactive and hands-on scientific exhibits, which flow across multiple levels in a building that is a creative, ecologically "green" architectural design, situated in the heart of downtown Dallas. Conference members enjoyed a "strolling" catered dinner, which progressed from the upper exhibits through to the entry-level atrium, where dinner culminated with dessert, coffee and discussion.

The workshop was generously supported by Brookhaven National Laboratory (BNL), CERN, DESY, Fermilab, Jefferson Lab, the National Science Foundation (NSF), the US Department of Energy (DOE) and the SMU.

The workshop demonstrated how "DIS and related subjects" permeates a broad range of physics topics, from hadron colliders to spin physics, neutrino physics and more. There is still much work to be done and information to be extracted from the latest experiments. The good news is that the DIS workshop series will continue next year, with DESY hosting DIS2016 in Hamburg, Germany, from 11 to 15 April 2016.

● For more details, see www.dis2015.org.

Explorers of 'strange world' get together in Sendai for HYP2015

Conference participants in Sendai (Japan). (Image credit: HYP2015.)

HYP2015, the 12th International Conference on Hypernuclear and Strange Particle Physics, took place from 7 to 12 September in Sendai, Japan, where around 200 participants from 20 countries gathered at Tohoku University.

Since 1982, the HYP conferences have been held every three years to discuss nuclear and hadron physics with strangeness. The main subjects are the production and structure of hypernuclei and strange hadrons, as well as baryon–baryon and meson–baryon interactions with strangeness. The subjects have been extended to low-energy aspects of QCD, dense and cold matter, and implications for neutron stars, and hadronic and nuclear systems with heavier flavours.

Experimental results and plans at J-PARC, JLab, GSI/FAIR, MAMI, DAΦNE, SPring-8, RHIC and the LHC were presented. A highlight was new data from MAMI and J-PARC, which confirmed the strange phenomenon that a Λ hyperon largely breaks the charge symmetry in a nucleus. Concerning the K^-pp bound system, a new positive signal from J-PARC was presented, while other experiments at GSI, SPring-8 and J-PARC have not caught any clear signal yet. Theoretical progress was reported in approaches including *ab-initio* calculations (starting from basic nuclear forces) of hypernuclei and lattice QCD calculations of baryon–baryon interactions.

Besides plenary and parallel sessions, topical sessions on "Hypertriton lifetime", "YN scattering experiments" and "Hyperon puzzle in neutron stars" were organised. Recently, heavy-ion collision experiments at RHIC, the LHC and GSI reported the lightest hypernucleus, ${}^3_\Lambda H$ (hypertriton), has a lifetime much shorter than theoretically expected. It is agreed that the discrepancy should be solved by further experimental and theoretical work. The lack of low-energy hyperon–nucleon (YN) scattering data has long been a problem in this field, and ongoing plans and prospects of scattering experiments were discussed in detail. "Hyperon puzzle" is a hot topic in strangeness nuclear physics. Hyperons are predicted to appear in high-density nuclear matter in neutron stars, based on our knowledge of YN and YY interactions, but this results in a softening of the nuclear-matter equation of state, and cannot support recently observed heavy neutron stars with twice the solar mass. To solve this serious discrepancy, several theoretical approaches were proposed and intensive discussions took place. The proceedings will be published in the *JPS Conference Proceedings*.

● Visit lambda.phys.tohoku.ac.jp/hyp2015/.

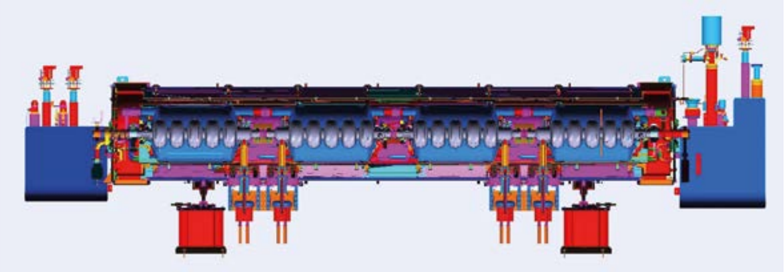
Workshops

Workshop on future electron–hadron colliders at CERN

In June, CERN hosted the annual workshop on upgrading the LHC with a powerful electron accelerator to enable electron–proton (and –ion) collisions in one interaction region. The Large Hadron electron Collider (LHeC) would use an energy recovery linac (ERL) to achieve 1000 times the luminosity in electron–proton scattering, compared with HERA, with a centre-of-mass energy above 1 TeV. The ERL principle is also considered for the configuration of a 3.5 TeV electron–proton collider that would use the 50 TeV proton beam of the Future Circular Collider (FCC-eh).

A scientific colloquium opened the workshop and introduced LHeC (FCC-eh)-related developments on the accelerator, detector and physics issues to the audience. The LHeC is being designed for concurrent operation with the LHC. This leads to significant cost reductions in possibly realising a far-reaching electron–hadron (proton and ion) physics programme. Moreover, this may transform the LHC into a precision Higgs facility, i.e. with increased precision and new opportunities using electron–proton collisions, and much reduced theory uncertainties for proton–proton Higgs physics.

Guido Altarelli spoke about the "Importance of deep inelastic scattering in the 21st century". His talk was followed by an impressive list of "Novel ideas" presented by Stan Brodsky, the other prominent theorist and member of the International Advisory Committee (IAC) chaired by Director-General emeritus of CERN, Herwig Schopper. Exciting prospects were presented on precision measurements in the top and Higgs sectors leading beyond the Standard Model, including a striking Higgs self-coupling sensitivity at the FCC-eh.



Sketch of the cryo-module housing four 802 MHz cavities. Each cavity contains five cells. This configuration is currently being designed by a collaboration of CERN and Thomas Jefferson Laboratory for the LHeC. In its current default configuration, the electron-beam energy in the LHeC achieves 60 GeV in three steps. The beam is accelerated by two linear accelerators, each comprising 140 such modules housed in a tunnel one third of the LHC in circumference. (Image credit: JLab.)

Further physics highlights concerned nuclear structure, important for heavy-ion physics and the understanding of physics at high parton densities; the latter is also required for ultra-high-energy neutrino physics exploring the far universe. Software challenges in detector development were also reviewed in detail. Due consideration was also given to the installation of the LHeC detector within a regular LHC shutdown, its synchronous operation during the HL-LHC phase, and a first design was presented of FCC-eh apparatus.

Much attention was given to ERL-related technology progress, especially on super-conducting radio frequency (SCRF) cavities (see figure), high-current electron sources and the recovery of beam power. As an intermediate step, an ERL facility delivering about 1 GeV energy electrons at high currents of tens of mA was considered. Such a facility would have a number of first-class potential physics applications related to photonuclear reactions and low-energy electromagnetic, as well as weak electron–proton interactions. However, the IAC recommended focusing on technical developments in international collaboration, with the aim to verify and optimise the principal accelerator design choices. The LHeC will be further developed in a three-year R&D programme, with the objective to maintain the option for moving forward when the European context is clearer and the Run 2 LHC results become available.

● For more details, see lhec.web.cern.ch.

EMMI workshop kicks off at CERN

Group photograph of the EMMI workshop participants. (Image credit: EMMI.)

The first workshop on antimatter, hypermatter and exotica production at the LHC was held at CERN on 20–22 July. The workshop was supported by the ExtreMe Matter Institute (EMMI) at GSI in Darmstadt (Germany). EMMI aims to foster research topics such as the properties of quark–gluon plasma and the phase structure of strongly interacting matter, the structure and dynamics of neutron matter, electromagnetic plasmas of high-energy density, ultra-cold quantum gases and extreme states in atomic physics.

The LHC is an ideal factory for anti- and hypermatter because heavy ions colliding at ultra-relativistic energies produce a huge number of quarks and antiquarks in equal amounts. An interesting feature of the ion collisions at the LHC is that s and $\bar{s}$ quarks are as abundant as u and d quarks.

The aim of the workshop was to discuss in depth the wealth of results on antimatter, hypermatter and exotic bound states (including pentaquarks, hexaquarks and dibaryons) obtained so far at the LHC using the data collected with pp, Pb–Pb and p–Pb collisions. Results obtained at other accelerators were also examined, together with a broad overview of the different theoretical approaches.

More than 50 scientists from around the world contributed to stimulating discussions in which the interplay between experimental results and their theoretical interpretation was essential. Out of the 27 invited talks, 10 were delivered by young scientists, providing them with an excellent opportunity to present their work in an informal and challenging environment.

A major outcome of the workshop was a complete overview and improved understanding of the data collected during LHC Run 1, as well as data from non-LHC experiments at lower energies. A heavily debated topic was the production of light antinuclei (from deuterons to ^{4}He) in heavy-ion collisions, and their interpretation through two competing models: the thermal production mechanism and production through coalescence. Furthermore, the production of Λ hypernuclei (nuclei in which one nucleon is replaced by a Λ hyperon) at different energies and with different production reactions was presented. These data were discussed in view of the open puzzle of hypernuclear physics, namely the unexpected low value of the hypertriton ($^3_\Lambda$H) lifetime measured in heavy-ion collisions. Finally, the state-of-the-art of the search for possible exotic bound states, such as the H-dibaryon, was presented. Possible measurements to look further for the discovery of these states were elaborated in a fruitful exchange between theorists and experimentalists.

● For more information, see https://indico.gsi.de/conferenceDisplay.py?confId=3767.

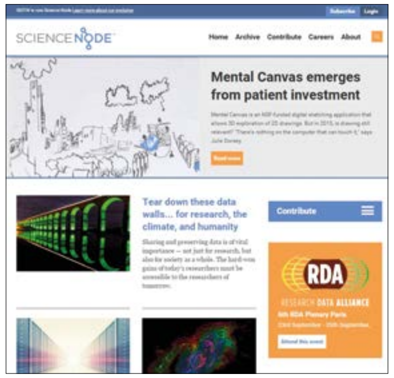
New publications

iSGTW relaunches as The Science Node

Earlier this year, the online magazine *International Science Grid This Week* (iSGTW) celebrated its 10th anniversary. Now, this free publication, which is run jointly by CERN in Europe and Indiana University in the US, has relaunched as *The Science Node*.

With its more memorable name, *The Science Node* will continue to report on research made possible by distributed and high-performance computing technologies. The publication will also feature the latest news and in-depth analysis related to networking, big data, volunteer computing, "the internet of things", citizen science and much more.

Find out more at www.sciencenode.org. If you're interested in contributing to *The Science Node*, please contact the editorial team at info@sciencenode.org.



The Science Node *was launched in September. (Image credit: The Science Node.)*

On 15 September, Helsinki Institute of Physics and Tampere University of Technology announced the launch of a new Business Incubation Centre (BIC) of CERN technologies. The Finnish BIC joins a network of six other such centres already established across Europe. Similarly to the others, it will connect science with industry and support the formation of new businesses from scientific research. CERN's technologies are already available through a variety of schemes, ranging from R&D partnerships to licences and consultancy. With the BIC scheme, CERN supports new companies and small businesses in the development and exploitation of innovative ideas in fields related to the laboratory's activities. In particular, CERN contributes with the transfer of knowledge and know-how through technical visits to the organisation, support for the BIC and preferential-rate licensing of CERN intellectual property. The new Finnish Business Incubation Centre will work in collaboration with CERN's Knowledge Transfer Group to encourage entrepreneurs to turn technology developed at CERN into useful, marketable ideas. The partnership agreement was signed at CERN. From left, head of CERN's Knowledge Transfer Group, Giovanni Anelli, CERN's Director-General, Rolf Heuer, the Finnish ambassador to Switzerland, Päivi Kairamo, HIP's director, Juha Äystö, TUT's president, Markku Kivikoski, and professor, director of HIP's Technology Programme, Saku Mäkinen. (Image credit: CERN.)

OBITUARIES

Jacob Bekenstein 1947–2015

Jacob (Yacov) Bekenstein, a faculty member of the Racah Institute of Physics of the Hebrew University, Jerusalem, Israel, passed away on 16 August 2015 while visiting the Department of Physics in Helsinki.

Jacob made seminal contributions to the understanding of the properties of black holes and information storage in quantum field theory and general relativity. His powerful tool was *Gedankenexperiments*. This approach (in English, "thought experiments") has played a very important role in the developments of new ideas in physics: Galileo envisaged falling bodies, Maxwell had demons, Einstein chased light rays and studied elevators and Schrödinger mulled over the fate of cats. Jacob Bekenstein took these experiments to a whole new level.

He revolutionised the understanding of black holes after performing a *Gedankenexperiment* upon the suggestion of his adviser at Princeton University, John Wheeler. In the experiment, the content of a teacup was poured into a black hole. Jacob was able to transform the implied threat of the reduction of entropy in this very esoteric process (in apparent violation of the second law of thermodynamics) into the totally unexpected realisation that black holes have thermodynamical properties. It was a triumph of the human spirit. Not only did he ascribe to black holes properties such as entropy, which reflects the number of degrees of freedom, but he also brought about a revolution in the deep understanding of thermodynamics and the structure of space as seen at high-enough energies, where black holes and their like emerge and play a role.

Pioneering study

For well over a century, textbooks have been teaching us that thermodynamical properties such as entropy are extensive, namely that they are proportional to the volume of the system under study. However, for reasons of consistency, Jacob decreed that black holes are objects whose thermodynamical properties must be proportional only to the area of the system. The body of work in which these ideas were developed and argued dates from 1972. As the years pass, and even though the full implications of this deep insight are yet to be understood, appreciation of this pioneering study is only increasing.

Since the beginning of his work, Jacob pointed out the crucial role played by

Jacob Bekenstein. (Image credit: Bekenstein family.)

the properties of processing information in unlocking the secrets of black-hole and quantum gravity. His research led him to suggest bounds on the amount of information that can be stored in a given volume of space–time. This bound is called the "Bekenstein bound", and has direct implications on theories in which gravity seems to play no role. Jacob's work, based again on *Gedankenexperiments*, raised a great deal of interest as well as controversy. He published it in 1981, and it has since passed several refinements and generalisations.

The very special nature of black holes uncovered by Jacob increased the realisation that information, in certain interesting circumstances at the very least, is stored on the boundary of those systems. This general feature was named "holography" – a concept borrowed from quantum optics. In particular, in one set of cases, that information is encoded in the form of a quantum-field theory where gravity is not even present. This goes under the name of AdS/CFT correspondence. Issues related to AdS/CFT correspondence are still the subject of active research in 2015, more than 40 years after Bekenstein's seminal paper appeared.

Physics may be about uncovering the objective secrets of nature, but it is done by humans, and most humans appreciate due recognition and credit. Jacob's ideas in the 1970s encountered both significant resistance and attempts to diminish his role. Not least from Stephen Hawking, who briefly mentions Bekenstein's role in his bestselling book *A Brief History of Time*. He writes: "I was motivated partly by irritation with Bekenstein, who I felt misused my discovery." And then: "However, it turned out in the end that he [Bekenstein] was basically correct, though in a manner he had certainly not anticipated."

This reflects the enormous pressure that the 25 year-old Jacob had to withstand, essentially all alone. Jacob who, while being rather shy was very opinionated, answers Hawking's remarks in his book *Of Gravity, Black Holes and Information*, where he writes: "I cannot, of course, do anything about another's anger but…Nobody can be held to blame for giving in a published result a novel interpretation of his own." He also mentions that "I almost lost confidence then." One can only imagine the strength he needed to stick to his intuition. The main argument against him at the time was the conventional wisdom that black holes should have zero temperature and thus supposedly no entropy. So much for conventional wisdom. Out of this cocktail of emotions that Bekenstein and Hawking brewed, one following the other, breakthroughs came in the understanding of the physical properties of black holes.

A dedicated teacher

As mentioned previously, Jacob was highly opinionated. In his book, one can find critical remarks on aspects of string theory, as well as a line such as "aspiring students, beware" with regards to string theory and "beware of cheap interdisciplinary fads". I venture to say that in my opinion, some of this was self-critique, because both string theory and Jacob's breakthroughs relied on the consistency of physical structures and seem painfully far from any near-future experimental verifications. In recent years, Jacob actually searched for some experimental evidence for quantum aspects of gravity itself. He was an excellent and dedicated teacher, and as such he also encouraged students to study advanced mathematics and improve their mastery of the English language.

At the Racah Institute of Physics, the high-energy theorists sit on the higher floor; nevertheless, Jacob seemed to have a quite guarded respect for the field. He was very interested in the results coming (and not coming) out of the LHC.

Part of Jacob's personality was that he practised religion in a private manner. He was named after Jacob in the bible, about whom it is said that he struggled with a formidable stranger (an angel, according to some), and did not lose. Very few faced the formidable challenges of presenting a theory of gravity with as much success as Jacob Bekenstein. One is also told about the biblical Yacov that he dreamed about: a ladder grounded on Earth and reaching heaven on which there was motion upwards and downwards. Jacob always made every research effort to be grounded on the Earth, but he did not shy away from climbing the ladder and bringing back his insights.

He will be dearly missed.

Jacob (Yacov) David Bekenstein was born in Mexico City on 1 May 1947. His father, Joseph Bekenstein, worked as a carpenter, and his mother, Esther (Nee) Vladaslavotsky, was a homemaker. They were Jewish immigrants from Poland to Mexico. He went on to graduate from Princeton University, obtaining a PhD in 1972 under John Wheeler. After time as a postdoctoral fellow at the University of Texas in Austin, he moved to the Ben-Gurion University of the Negev in Beersheba, where he eventually became chairman of the astrophysics department. In 1990, he joined the faculty of the Hebrew University of Jerusalem.

His awards include the Rothschild, Israel, Wolf and Einstein prizes in Physics. He was a member of the Israeli Academy of sciences and humanities.

Jacob is survived by his wife Bilha, his daughter Rivka (a PhD student in physics at the Technion) and his sons Yehonadav (a condensed-matter physicist, now a postdoctoral fellow at UC Berkeley) and Uriya (a PhD student in biology at the Hebrew University), as well as by his six grandchildren.

● *Eliezer Rabinovici.*

Bernard D'Espagnat 1921–2015

Bernard D'Espagnat, physicist and philosopher, passed away on 1 August 2015.

His father was a famous post-impressionist; one of his paintings can be seen in Musée d'Orsay. Bernard D'Espagnat entered the Ecole Polytechnique in Paris, but his studies were interrupted when he was sent to Vienna during the German occupation period for forced labour. After the war, he came back to France and finished his studies, starting his PhD in the Leprince Ringuet laboratory at the Ecole Polytechnique. After a year spent in Chicago he went to CERN, which was in its infancy in 1954. Indeed, D'Espagnat was the first member of the CERN Theory Group in Geneva (at that time there was another group of theorists affiliated to CERN but based in Copenhagen).

A year later, in 1955, he convinced Jacques Prentki, whom he had met at Ecole Polytechnique, to join him at CERN. As we know, Prentki played a very important role for the organization until his death in 2009, while D'Espagnat left CERN and became professor in Orsay (France) in 1961. The early work of D'Espagnat was mostly in collaboration with Prentki, mainly searching for symmetries of hadrons and their decays. In 20 publications, they had developed their own theoretical model, and later worked with Abdus Salam (1979 Nobel prizewinner) on the "global-symmetry" theory. Their exploratory work was very useful, despite the fact that, in 1961, Gell-Mann and Ne'eman independently (and, in parallel, Speiser and Thirring-Wess) developed the "good model" – the octet model in SU3. Indeed, looking for order in the jungle of hadrons is like playing the archeologist: you dig in different directions and different places and finally someone finds the truth.

In 1961, D'Espagnat published a paper, which I consider to be a turning point in

Bernard D'Espagnat. (Image credit: Templeton Prize/Laurence Godart.)

his career. Two years earlier, the American physicists Day, Snow and Sucher had proposed a mechanism in which a negatively charged particle captured by a proton could cascade down to an S quantum state. In his paper, D'Espagnat pointed out that if a proton and an antiproton in an S state annihilate into a pair of neutral K^0 mesons, it will unavoidably be a K^0_1 and a K^0_2 meson (this was before CP violation was discovered in 1964; today, these states are called K^0_s and K^0_1). D'Espagnat's theory was confirmed in an experiment carried out at CERN in 1962.

Instant knowledge

The theory implies that, as seen in the annihilation of a proton–antiproton, if a K^0_s is detected, one knows instantly that the other decay product is a K^0_1. The information seems to propagate at a velocity greater than the speed of light. John Bell later called this mechanism the "Bertlmann effect". The name comes from Reinhold Anton Bertlmann, a physicist living in Vienna who had the habit of wearing one blue sock and one red sock. If he put his socks in two envelopes and sent one to Moscow and the other to Geneva, the person who received the sock in Geneva would know instantly the colour of the sock received in Moscow. This is classically acceptable, but in quantum mechanics there is a subtle effect called entanglement, for instance seen in the decay of a π_0 into two photons that show correlations in their polarizations. In fact, this is only an example of the many things that are difficult to swallow in the so-called "Copenhagen interpretation" of quantum mechanics. Even Einstein, who initiated quantum mechanics with his theory of the photoelectric effect, did not believe in it. He even said: "God does not play dice," criticizing the probabilistic aspect of the theory. However, John Bell proposed tests of quantum mechanics, which were experimentally checked by the French physicist Alain Aspect. In fact, in the ordinary life of physicists, quantum mechanics is tested every day. For instance, the energy levels of atoms are predicted with incredible accuracy by quantum mechanics.

In this complex situation, D'Espagnat tried to find a way out. His views, almost mystical, are certainly respectable. They imply a veiled reality. He has written several books in a marvellous style about this, in particular *Conceptual Foundations of Quantum Mechanics*. Others, Like Roland Omnès, have different points of view. D'Espagnat was rewarded by the prestigious Templeton prize in 2009, and was a member of the Académie française des Sciences Morales et Politiques. He was full of charm. We will sorely miss him

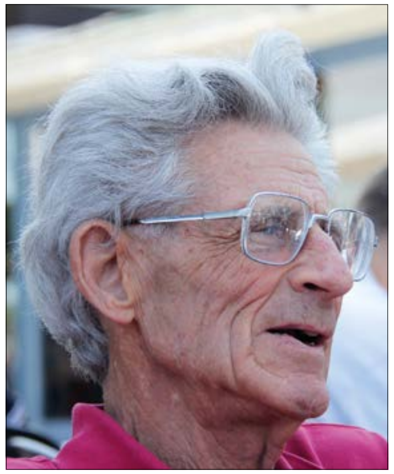
● *André Martin.*

Raymond Stora 1930–2015

A great figure of theoretical physics, Raymond Stora passed away on 20 July. He leaves behind an impressive body of work in the difficult domain of quantum field theory, as well as a vast empty space in the community of theoretical physicists.

Taking an equal interest in the use of quantum field theory in particle physics as in its mathematical structures, Raymond Stora significantly participated for more than half a century in important developments such as the relativistic invariance in quantum field theory or the instanton theory. In the 1970s, his work with C Becchi and A Rouet in the framework of the renormalisation of non-Abelian gauge theories – a basis for the unification of electromagnetic and weak interactions – led to the famous "BRS transformation", named after its authors, and which cannot be ignored by any student of theoretical physics.

Raymond Stora defended his thesis at MIT, then became a member of the Department of Theoretical Physics at the CEA in Saclay, from 1957 to 1970. He then joined the CNRS and became director of the Laboratory of Theoretical Physics in Marseilles. At the beginning of the 1980s, after several long-term visits to CERN, his career led him to Annecy, where he played a fundamental and vital role in the development of the group that was to become the LAPTh, Laboratory of Annecy-le-Vieux of Theoretical Physics.



Raymond Stora. (Image credit: Stora family.)

In the last few years, Raymond Stora was emeritus director of research at the CNRS, as well as emeritus researcher at the Theory Division of CERN.

International reach

Raymond Stora occupied several positions of responsibility at various national and international levels, in particular as president of the Theoretical Physics Commission of the CNRS and as director of the School of Physics at Les Houches. He was also awarded several national and international scientific prizes: the Joannidès Prize of the French Academy of Sciences, the Ricard Prize of the French Society of Physics, the Max-Planck Medal, and the Dannie Heineman Prize of Mathematical Physics. He was a corresponding member of the French Academy of Sciences as well as a Chevalier de la Légion d'Honneur.

A brilliant mathematical physicist and a particularly gifted particle physicist, Raymond Stora was a man of immense culture beyond the sciences. He loved arts and books, especially those of the 16th century, because they were the first printed texts to be published. But his main concern was in helping his fellow human beings to realise their full potential. He was a gentle, kind and fair man, exceptionally generous with the most precious thing: his time. With his eclectic knowledge, he spared no effort in guiding, correcting and advising people, encouraging without ever judging others, particularly young physicists. A man of conviction, he was driven by an incredible intellectual vivacity and extraordinary foresight. He was both demanding and tolerant, in his work as well as in his personal life: demanding towards himself, demanding for the truth, tolerant of different scientific ideas and tolerant of others.

Raymond was a master, a respected and beloved man. Some scientists deserve the term of humanist, and Raymond Stora was definitely one of them.

● *His friends and colleagues.*

Prize

IUPAP Young Scientist Prize In Nuclear Physics

This prize was established by IUPAP in 2005 at the time of the General Assembly in Cape Town, South Africa.

The purpose of this prize, which consists of €1000, a medal, and a certificate citing the recipient's contributions, is "To recognise and encourage very promising experimental or theoretical research in nuclear physics, including the advancement of a method, a procedure, a technique, or a device that contributes in a significant way to nuclear-physics research. Candidates for the prize must have a maximum of eight years of research experience (excluding career interruptions) following the PhD (or equivalent) degree."

Nominations by one or two nominators (and distinct from the nominee) are open to all experimental and theoretical nuclear physicists. The nomination package should contain, in addition to the nomination letter, at least two further letters of support, and the curriculum vitae of the nominee, which also contains the list of publications. Three prizes will ordinarily be awarded at the time of the tri-annual International Nuclear Physics Conference.

The deadline for nominations is 1 December 2015. The additional letters supporting the nomination should detail the expected significance of the contributions of the nominee to nuclear physics. To underline this, additional material such as published articles can be added to the nomination package. In particular, information that allows the selection committee to evaluate the nominee's contribution to, and its direct impact, on the field.

Nominations for prizes to be awarded at the next International Nuclear Physics Conference, to be held on 11 to 16 September 2016, in Adelaide, Australia, should be e-mailed, by 1 December 2015, to the chair of the IUPAP Commission of Nuclear Physics (C12), Professor Alinka Lépine-Szily, to alinka@if.usp.br, with the subject line "IUPAP prize nomination".

Correction

An unfortunate error crept in to the figure published on page 9 of the September issue. The units used in the ordinate of the graph in figure 5 had (pp) instead of (pb), which stands for "picobarn". The error has been corrected in the online and archived version of the journal.

Recruitment

For advertising enquiries, contact *CERN Courier* recruitment/classified, IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK.
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California Institute of Technology (Caltech)
Massachusetts Institute of Technology (MIT)

The Laser Interferometer Gravitational-Wave Observatory (LIGO) has as its goal the development of gravitational wave physics and astronomy. The LIGO Laboratory is managed by Caltech and MIT, and is funded by the National Science Foundation. It operates observatory sites equipped with laser interferometric detectors at Hanford, Washington and Livingston, Louisiana. A major upgrade (Advanced LIGO) has just been completed and the new LIGO detector has just begun a series of observing runs to search for gravitational waves. A vigorous LIGO Laboratory R&D program supports the development of enhancements to the LIGO detector as well as astrophysical data analysis, and development of future detector technologies.

The LIGO Laboratory anticipates having one or possibly more postdoctoral research positions at one or more of the LIGO sites – Caltech, MIT and at the two LIGO Observatories in Hanford, WA and Livingston, LA – beginning in Fall 2016. Hires will be made based on the availability of funding. Successful applicants will be involved in the operation of LIGO itself, analysis of LIGO data, both for diagnostic purposes and astrophysics searches, as well as the R&D program for future detector improvements. We seek candidates across a broad range of disciplines. Expertise related to astrophysics, modeling, data analysis, electronics, laser and quantum optics, vibration isolation and control systems is desirable. Most importantly, candidates should be broadly trained physicists, willing to learn new experimental and analytical techniques, and ready to share in the excitement of building, operating and observing with a gravitational-wave observatory. Appointments at the post-doctoral level will initially be for one-year with the possibility of renewal for up to two subsequent years.

Applications for post-doctoral research positions with LIGO Laboratory should indicate which LIGO site (Caltech, MIT, Hanford, or Livingston) is preferred by the applicant. Applications should be sent to **HR@ligo.caltech.edu** (Electronic Portable Document Format (PDF) submittals are preferred). Caltech and MIT are Affirmative Action/Equal Opportunity employers. Women, minorities, veterans, and disabled persons are encouraged to apply.

Applications should include curriculum vitae, list of publications (with refereed articles noted), and the names, addresses, email addresses and telephone numbers of three or more references. Applicants should request that three or more letters of recommendations be sent directly to **HR@ligo.caltech.edu** (Electronic Portable Document Format (PDF) submittals are preferred). Consideration of applications will begin December 1, 2015 and will continue until all positions have been filled.

Caltech and MIT are Affirmative Action/Equal Opportunity Employers
Women, Minorities, Veterans and Disabled Persons are encouraged to apply
More information about LIGO available at www.ligo.caltech.edu

POSTDOCTORAL FELLOWS
Kavli Institute for the Physics and Mathematics of the Universe, The University of Tokyo, Japan

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

The "Kavli Institute for the Physics and Mathematics of the Universe" (Kavli IPMU) is an international research institute with English as its official language established in October 2007. The goal of the institute is to discover the fundamental laws of nature and to understand the universe from the synergistic perspectives of mathematics, statistics, theoretical and experimental physics, and astronomy. We are particularly interested in candidates with broad interests and a willingness to interact with people across disciplines.

We intend to offer more than a dozen postdocs with three-year terms. We seek to build a diverse, highly interactive membership, and female and international applicants are strongly encouraged. We have generous travel support for our postdocs, and encourage full-time members to be away from the Institute for between 1 and 3 months every year.

The focus of Kavli IPMU includes but is not limited to: all areas of mathematics (e.g. algebra, geometry, analysis, and statistics); string theory and mathematical physics; particle theory, collider phenomenology, beyond the standard model physics phenomenology; cosmology and astrophysics theory; astronomy and observational cosmology; and particle and underground experiments. We are leading efforts on the XMASS dark matter experiment, the KamLAND-Zen neutrino experiment, the Hyper Suprime-Cam (HSC) project for weak lensing surveys and Prime Focus Spectrograph (PFS) for the dark energy at the Subaru Telescope, GADZOOKS! at Super-Kamiokande, the Belle II experiment, T2K long baseline neutrino experiment, SDSS-IV for a survey of galaxies, POLARBEAR CMB B-mode polarization measurement, and R&D for future large neutrino detectors and the LiteBIRD satellite.

We have embarked on a new frontier field of statistical computational cosmology. We plan to develop applications to statistically extract cosmological parameters from a huge dataset from the Subaru wide field survey. We have a few positions for this project which is supported by CREST from Japan Science and Technology Agency (JST).

The search is open until filled, but for full considerations please submit the applications and letters on the application form by Dec 1, 2015

Further information can be found here:
http://www.ipmu.jp/job-opportunities

For inquiries please contact: **application-inquiry@ipmu.jp**

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

ACCELERATOR CONTROLS.

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

DESY

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

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

The position

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

Requirements

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

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

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

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

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

HELMHOLTZ | ASSOCIATION

FACULTY POSITION IN THEORETICAL HIGH ENERGY PHYSICS

Department of Physics and Astronomy
Purdue University

The Department of Physics and Astronomy at Purdue (**www.physics.purdue.edu**) seeks applications for a faculty position at the level of Assistant Professor in the field of theoretical high-energy physics. The areas of current interest in the Department include string theory and applications, phenomenology of and beyond the standard model, and theoretical cosmology. Candidates are required to have a doctoral degree in physics or related field and a documented record of research accomplishments. Candidates are expected to develop a vigorous research program, supervise graduate students, and teach undergraduate and graduate level courses. Applicants should send a curriculum vitae, publication list, a brief statement of present and future research plans, a statement of teaching philosophy and arrange for three letters of recommendation. Electronic submission is preferred: **https://www.physics.purdue.edu/searches/app/**.
Questions regarding the position and search should be directed to either **Martin Kruczenski (markru@purdue.edu)** or **Sergei Khlebnikov (skhleb@purdue.edu)**.
Applications completed by December 18, 2015 will be given full consideration, although the search will continue until the position is filled. A background check is required for employment in this position.

Purdue University is an EEO/AA employer. All individuals, including minorities, women, individuals with disabilities, and protected veterans are encouraged to apply.

International Max Planck Research School
Quantum Dynamics
in Physics, Chemistry and Biology

PhD Scholarships

within the International Max Planck Research School for Quantum Dynamics in Physics, Chemistry and Biology

The International Max Planck Research School for Quantum Dynamics in Physics, Chemistry and Biology (IMPRS-QD) is a graduate school offering a doctoral degree program in these disciplines. The IMPRS-QD is a joint initiative of the Max Planck Institute for Nuclear Physics (MPIK), the Heidelberg University, the German Cancer Research Center (DKFZ), the Max Planck Institute for Medical reserach (all in Heidelberg) and the Heavy Ion Research Center (GSI) in Darmstadt.

Membership in the Heidelberg Graduate School of Fundamental Physics is envisaged. Further information may be found on the school's website http://www.mpi-hd.mpg.de/imprs-qd/.

Applications of students from all countries are welcome. To be eligible for PhD studies at the University of Heidelberg, applicants should have a Master of Science degree (or equivalent). Applicants who do not have a Master thesis may be accepted if they can prove their ability to carry out independent research projects. International applicants whose mother-tongue is not English or German have to provide a proof of English proficiency. At equal level of qualification, candidates with disabilities are given preference. Women are encouraged to apply.

Interested students are asked to apply via web form at: http://www.mpi-hd.mpg.de/imprs-qd/appladmiss.html.

The application deadline is 21 November 2015.

OMA

Open Positions in the OMA project

Cancer is a major social problem and it is the main cause of death between the ages 45-65 years. Radiotherapy plays an essential role in the treatment of cancer.

The Optimization of Medical Accelerators (OMA) is the aim of a new European research and training network.

OMA addresses the challenges in treatment facility design and optimization, numerical simulations for the development of advanced treatment schemes, and in beam imaging and treatment monitoring.

The network is currently offering Fellowships to 15 talented, energetic, highly motivated early career researchers that will be employed by the different beneficiary partners across Europe. Possibilities for enrolling into a PhD programme exist.

Each researcher will benefit from a wide ranging training that will take advantage of both local and network-wide activities. Excellent salaries will be offered. Most positions are for starting on 1st October 2016.

Application deadline:
28th February 2016

Contact and further detail:
Prof. Dr. Carsten P. Welsch
Cockcroft Institute/University of Liverpool
WA4 4AD Warrington, UK
carsten.welsch@cockcroft.ac.uk

www.oma-project.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 675265.

Bookshelf

Qu'est-ce que le boson de Higgs mange en hiver et autres détails essentiels
By Pauline Gagnon
MultiMondes
Hardback: €29
E-book: €19
Also available at the CERN bookshop

Pauline Gagnon est bien connue dans la communauté des expérimentateurs au LHC car, en plus de sa contribution à l'expérience ATLAS, elle a été membre du groupe de communication du CERN de 2011 à 2014 et sur le blog *Quantum Diaries* elle a couvert de nombreux évènements récents liés à l'activité scientifique du laboratoire.

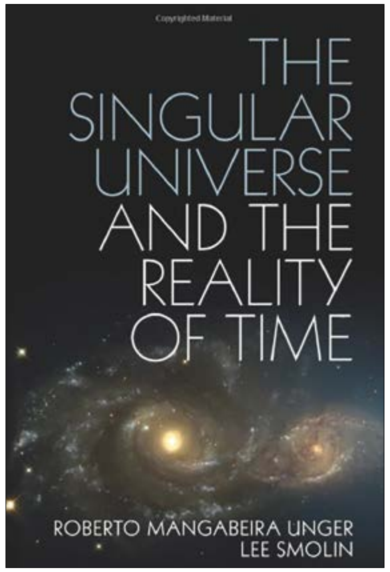
Le titre de son livre rédigé en français, « Qu'est ce que le Boson de Higgs mange en hiver » est quelque peu trompeur, car les propos de l'auteur vont bien au delà de la description du mécanisme de Brout-Englert & Higgs et de la découverte expérimentale du boson de Higgs en 2012. Son livre offre non seulement une vue d'ensemble de la physique étudiée dans les expériences au LHC, du complexe d'accélérateurs et de détecteurs réalisés pour cette recherche et des méthodes statistiques employées pour la découverte du Boson de Higgs, mais inclut aussi un chapitre qui décrit l'organisation originale (et probablement unique) des grandes collaborations internationales en physique des hautes énergies ainsi qu'un chapitre sur les transferts de technologie et de connaissance de notre domaine vers le monde économique et le grand public.

Le livre décrit aussi les liens qui relient la physique des hautes énergies à l'astrophysique, avec un chapitre consacré aux évidences expérimentales qui ont amené à augurer de l'existence de la matière noire, et à une comparaison entre le potentiel de découverte de celle-ci par des expériences sur et hors accélérateurs. Un autre chapitre est consacré à la super-symétrie, la théorie actuellement la plus populaire au delà du modèle standard pour répondre aux questions que celui-ci ne peut résoudre, et aux défis qui attendent les expériences du LHC dans les prochaines années. Le livre se termine par la discussion d'un thème qui est quelque peu déconnecté mais cher au cœur de l'auteur, à savoir la question de la diversité (en particulier l'emploi des femmes) dans le monde de la recherche scientifique.

Le livre n'est pas destiné aux spécialistes mais cible le grand public. A cette fin, l'auteur a banni toute formule mathématique et utilise souvent des analogies pour introduire les différents concepts. Les parties plus complexes ou plus détaillées sont incluses dans des encarts séparés que le lecteur peut éventuellement sauter. Dans le même esprit, chaque chapitre se termine par un résumé d'une page environ qui permet une lecture abrégée du point traité, quitte à y revenir plus tard. Le style est simple et direct, avec souvent une pointe d'humour. Le discours n'est cependant pas superficiel, et il me semble que le livre s'adresse tout de même à des lecteurs avec une certaine connaissance scientifique de base, par exemple des jeunes étudiants qui veulent comprendre l'intérêt et les buts de la recherche en physique des particules.

● *Philippe Bloch, CERN.*

The Singular Universe and the Reality of Time: A Proposal in Natural Philosophy
By Roberto Mangabeira Unger and Lee Smolin
Cambridge University Press
Hardback: $20
E-book: $17



This is a book on natural philosophy, a field that the authors argue, and convincingly so, has not had much activity for a long time. It is definitely not a popularisation, although it is written clearly enough (and free of equations) that it should be accessible to most knowledgeable readers.

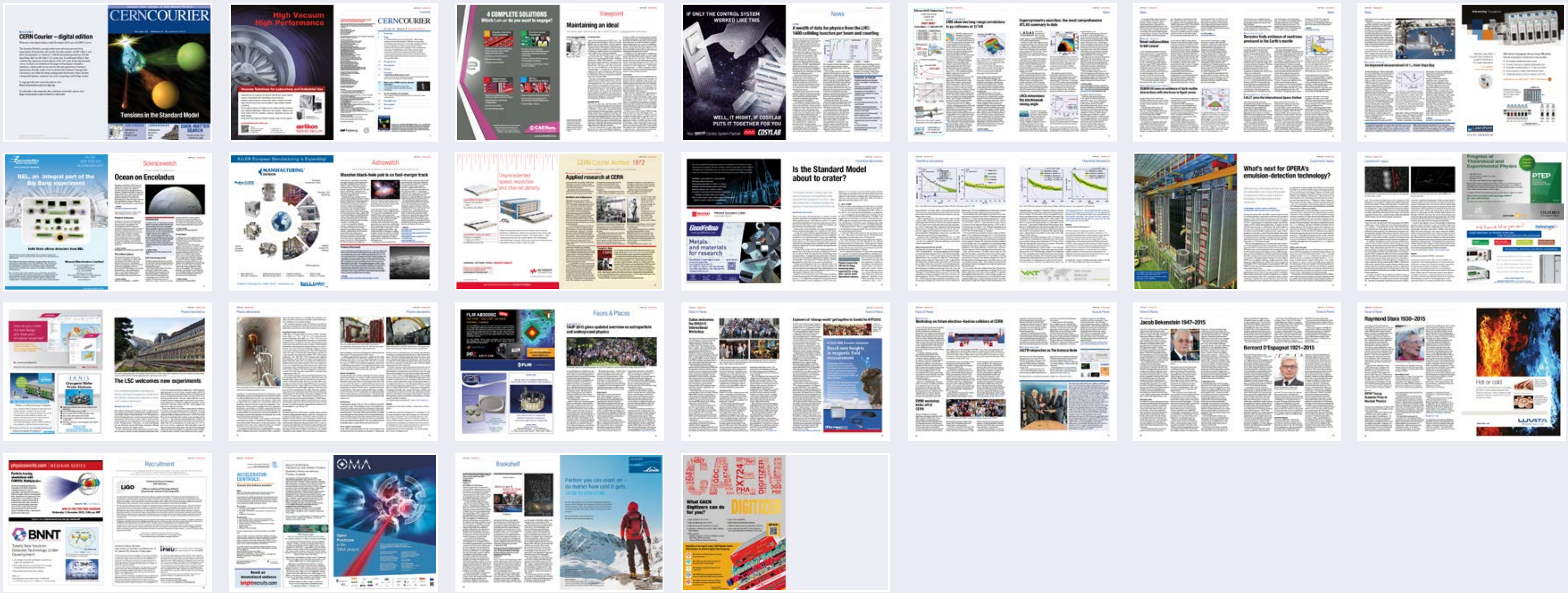
In many ways, this is two books: one of about 350 pages by Unger, a philosopher, and another of about 150 pages by Smolin, a physicist, each presenting overlapping but often dissenting views, together with a discussion of these differences. This means one can be quite comfortable reading it and agreeing or not, as each point is raised.

Perhaps the key idea is that history might play a role in determining why the universe is the way it is, in as fundamental a way as history determines much of biology. This takes on many of the fundamental assumptions that go into cosmology and physics, including the idea that the "laws" of physics are somehow hard-wired into the universe and that they could conceivably evolve. Indeed in biology, the laws that govern biology emerge as the space of living things evolves. This puts causal connections in the driving seat and is akin to taking the Darwinian viewpoint in biology over the creationist myth. A new view emerges on why things are the way they are – an alternative to some hypothetical "elegant(?)" future derivation of why, for example, masses and couplings are what they are.

The authors eschew some ideas that often occur today, including that of there being a multiverse with ourselves being in but one (the "singular" in the title means there is just one), and the idea that time is somehow not real and leading to a genuine history. They even argue that mathematics may not merit the ("prophetic", as they put it) role that we often give it.

It's a hard book to put down. Whether or not one agrees with the points that are raised, the book is nothing if not thought-provoking, and the ideas could well be revolutionary.

● *John Swain, Northeastern University.*



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